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FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

RECENT DEVELOPMENTS IN THE ABSORPTION
PROCESS FOR RECOVERING GASOLINE
FROM NATURAL GAS

BY

W. P. DYKEMA



WASHINGTON
GOVERNMENT PRINTING OFFICE
1919

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DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

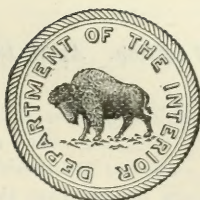
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RECENT DEVELOPMENTS IN THE ABSORPTION PROCESS FOR RECOVERING GASOLINE FROM NATURAL GAS.

By W. P. DYKEMA.

INTRODUCTION.

This report gives the results of a study conducted by the Bureau of Mines for the purpose of informing the petroleum industry on the recent progress in the development and application of the absorption process for recovering gasoline from natural gas. The work has been undertaken entirely with regard to plant practice and for the purpose of describing the features and the operation of units of the plants now in use, the improvements that have been made, and the reasons for any changes contemplated by the engineers in charge of the plants studied.

Throughout the United States the improvements in the absorption process that are under consideration by engineers not only widen practice so as to include gases at all pressures and percentages of gasoline content, but seem to be developing definite standards as to dimensions of towers, velocities of flow, saturation of oils, areas of cooling surfaces, and quantities of menstruum to be circulated. Although perfect practice has by no means been attained, the writer believes that a description of the current practice at various plants, including those obviously more efficient features that each plant has developed and uses at one or another stage of treatment, will interest and possibly help all persons operating or designing absorption plants.

ACKNOWLEDGMENTS.

The possibilities and the usefulness of a study of the absorption process by the Bureau of Mines were recognized and suggested by W. A. Williams, when chief of the petroleum division of the bureau. Chester Naramore, the present chief of the division, has shown untiring interest in this study and has given his hearty support and helpful guidance. Particular thanks are due Messrs. P. M. Biddison and Thomas R. Weymouth for much data regarding plant operation and construction. The writer acknowledges the courtesies extended and the information given him by Messrs. Guy L. Goodwin, J. J. Allison, W. P. Gage, W. R. Hamilton, J. D. Creveling, W. R. Finney, E. Hepner, E. T. Buckley, Carl Holt, D. L. Newton, and

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Much use has been made of Bureau of Mines publications^a on this and related subjects, also the publications of the Bureau of Standards.^b

PRODUCTION OF GASOLINE FROM NATURAL GAS.

The marketed production of gasoline recovered from natural gas sold in the United States during the years 1911 to 1917 is shown in Table 1 following.

TABLE 1.—Gasoline from natural gas marketed in the United States, 1911–1917.^c

1911.

State.	Number of operators.	Plants.		Gasoline produced.			Gas used.		Average yield in gasoline per M cubic feet.
		Number.	Daily capacity.	Quantity.	Value.	Price per gallon.	Estimated quantity.	Value.	
			<i>Gallons.</i>	<i>Gallons.</i>		<i>Cents.</i>	<i>Cubic feet.</i>		<i>Gallons.</i>
West Virginia.....	47	72	16,819	3,660,165	\$262,661	7.18	1,252,900,600	\$76,074	2.92
Ohio.....	26	39	6,454	1,678,985	118,161	7.04	469,672,000	37,574	3.57
Pennsylvania.....	43	50	5,669	1,467,043	109,649	7.47	526,152,663	52,615	2.79
Oklahoma.....	8	8	4,800	388,058	20,975	5.40	144,629,000	4,378	2.68
California.....	8	7	3,358	231,588	20,258	8.75	82,343,000	6,320	2.81
Colorado.....									
Illinois.....									
New York.....									
Kentucky.....									
	132	176	37,100	7,425,839	531,704	7.16	2,475,697,263	176,961	3.00

^a Allen, I. C., and Burrell, G. A., *Liquified products from natural gas*, Tech. Paper 10, 1912, 23 pp.; Calvert, W. R., *A preliminary report on the utilization of petroleum and natural gas in Wyoming, with a discussion of the suitability of natural gas for making gasoline* by G. A. Burrell, Tech. Paper 57, 1913, 23 pp.; Burrell, G. A., and Jones, G. W., *Methods of testing natural gas for gasoline content*, Tech. Paper 87, 1916, 26 pp.; Burrell, G. A., and Robertson, I. W., *The compressibility of natural gas at high pressures*, Tech. Paper 131, 1916, 11 pp.; Dean, E. W., *Motor gasoline; properties, laboratory methods of testing, and practical specifications*, Tech. Paper 166, 1917, 27 pp.; Burrell, G. A., Seibert, F. M., and Oberfell, G. G., *The condensation of gasoline from natural gas*, Bull. 88, 1915, 106 pp.; Burrell, G. A., Biddison, P. M., and Oberfell, G. G., *Extraction of gasoline from natural gas by absorption methods*, Bull. 120, 1917, 71 pp.

^b Edwards, J. D., *Effusion method of determining gas density*, Technologic Paper 94, Bureau of Standards, 1917, 30 pp.; United States standard tables for petroleum oils, Circular 57, Bureau of Standards, 1916, 64 pp.

^c Figures for 1911 to 1916 from *Mineral Resources of United States for 1916*, U. S. Geol. Survey, 1917, pp. 648–649; figures for 1917 supplied by U. S. Geol. Survey.

^d Includes gasoline produced in Kentucky which came from natural condensation in gas mains.

TABLE 1. Gasoline from natural gas marketed in the United States, etc.—Contd.

1912.

State.	Number of operators.	Plants.		Gasoline produced.			Gas used.		Average yield in gasoline per M cubic feet.
		Number.	Daily capacity.	Quantity.	Value.	Price per gallon.	Estimated quantity.	Value.	
			Gallons.	Gallons.		Cents.	Cubic feet.		Gallons.
West Virginia.....	66	97	22,366	5,318,136	\$513,116	9.6	1,972,882,212	\$163,749	2.8
Pennsylvania.....	69	83	10,524	2,041,109	217,016	10.6	722,730,117	62,010	2.8
Ohio.....	25	43	7,791	1,718,719	173,421	10.1	576,123,700	46,090	2.98
Oklahoma.....	11	13	11,910	1,575,644	99,626	6.3	701,044,300	24,901	2.25
Illinois.....	7	7	6,009	1,040,695	112,502	10.8	600,743,000	25,573	1.7
Colorado.....	2	2							
New York.....	1	1	2,008	a 386,876	41,795	10.8	114,273,000	9,662	3.4
Kentucky.....	1								
	186	250	61,268	12,081,179	1,157,476	9.6	4,687,796,329	331,985	2.6

1913.

West Virginia.....	63	115	31,930	7,662,493	\$807,406	10.54	2,981,119,000	\$181,337	2.57
Oklahoma.....	19	40	61,633	6,462,968	577,944	8.94	2,152,503,000	82,712	3.00
Pennsylvania.....	100	113	22,207	3,680,096	405,186	11.01	1,372,056,000	114,783	2.68
California.....	12	14	21,135	3,460,747	376,227	10.87	2,436,445,000	106,539	1.42
Ohio.....	25	41	8,142	2,072,687	212,404	10.25	744,226,000	63,233	2.79
Illinois.....	6	12							
Colorado.....	2	2							
New York.....	3	3	7,368	a 721,826	79,276	10.98	203,092,500	17,590	3.55
Kansas.....	1	1							
Kentucky.....	1								
	232	341	152,415	24,060,817	2,458,443	10.22	9,889,441,500	506,224	2.43

1914.

Oklahoma.....	35	58	74,793	17,277,555	\$1,113,059	6.44	5,738,549,000	\$273,940	3.01
West Virginia.....	65	121	34,460	9,278,108	691,899	7.45	3,005,292,000	172,396	2.58
California.....	17	19	32,360	7,581,309	633,517	8.36	5,129,709,000	197,066	1.48
Pennsylvania.....	96	119	21,456	4,611,733	359,402	7.79	1,560,064,000	125,690	2.89
Ohio.....	25	47	9,319	2,440,171	184,097	7.54	852,277,000	68,935	2.86
Illinois.....	7	14	5,300	1,164,178	100,331	8.62	462,321,000	43,017	2.52
Kansas.....	3	3							
New York.....	3	3							
Colorado.....	2	2	1,665	a 299,573	23,604	7.88	146,345,000	8,862	2.03
Kentucky.....	1								
	251	386	179,353	42,652,632	3,105,909	7.28	16,894,557,000	889,906	2.43

1915.

Oklahoma.....	35	63	111,463	31,665,991	\$2,361,029	7.46	8,791,881,000	\$435,512	3.60
California.....	18	20	40,775	12,835,126	975,397	7.60	8,006,888,000	288,669	1.60
West Virginia.....	66	114	34,422	10,853,608	927,079	8.54	3,526,575,000	150,918	2.30
Pennsylvania.....	116	139	22,754	5,898,597	569,873	9.66	1,838,034,000	186,325	2.73
Ohio.....	29	50	8,995	2,198,715	167,138	7.60	785,041,000	77,767	2.80
Illinois.....	8	15	8,760	1,035,204	80,049	7.73	451,663,000	34,405	2.29
Texas.....	1	1							
New York.....	4	4							
Louisiana.....	2	2							
Kansas.....	3	2	5,447	877,424	70,258	8.01	694,309,000	28,959	1.32
Colorado.....	2	2							
Kentucky.....	2	1							
	287	414	232,336	65,364,665	5,150,823	7.88	24,064,391,000	1,202,555	2.57

a Includes gasoline produced in Kentucky which came from natural condensation in gas mains.

b Includes gasoline resulting from natural condensation in gas mains.

TABLE 1.—Gasoline from natural gas marketed in the United States etc.—Contd.

1916.

State.	Number of operators.	Plants.		Gasoline produced.			Estimated quantity of gas treated.	Average yield of gasoline per thousand cubic feet of gas.
		Number.	Daily capacity.	Quantity.	Value.	Price per gallon.		
			<i>Gallons.</i>	<i>Gallons.</i>		<i>Cents.</i>	<i>M cubic ft.</i>	<i>Gallons.</i>
Oklahoma.....	77	116	233,077	48,359,602	\$5,865,145	12.13	24,749,454	1.954
West Virginia.....	105	147	98,659	18,765,056	3,025,293	16.12	104,664,536	.179
California.....	28	26	54,090	17,158,754	2,293,822	13.37	24,826,354	.691
Pennsylvania.....	167	195	46,487	9,714,926	1,726,173	17.77	38,490,621	.252
Ohio.....	40	55	18,391	2,638,571	470,804	17.84	5,435,759	.485
Illinois.....	17	32	12,070	2,260,288	262,664	11.58	1,338,594	1.688
Louisiana.....	7	7	10,661	2,113,159	269,564	12.76	907,153	2.329
Texas.....	3	4	6,688	1,292,811	201,023	15.55	948,485	1.363
Kentucky.....	5	5	11,300	725,467	141,347	19.48	5,614,613	.129
Kansas.....	4	3	3,030	215,000	35,030	16.29	1,026,635	.132
New York.....	7	6	1,025	249,055	40,283	16.17	102,819	2.422
Colorado.....								
	460	596	495,448	103,492,689	14,331,148	13.85	208,705,023	.496

1917.

Oklahoma.....	167	234	492,436	115,123,424	21,541,905	18.71	84,719,941	1.359
West Virginia.....	128	188	135,663	32,668,647	6,511,813	19.93	167,771,351	.195
California.....	45	49	99,761	28,817,604	4,438,022	15.40	45,351,247	.635
Pennsylvania.....	287	251	59,164	13,826,250	2,778,098	20.01	49,487,056	.279
Texas.....	10	11	32,550	6,920,405	1,149,441	16.61	12,677,216	.546
Ohio.....	49	61	25,137	5,439,560	1,051,376	19.33	30,062,141	.181
Louisiana.....	15	20	20,118	4,979,754	814,747	16.36	2,233,511	2.229
Illinois.....	33	55	17,392	4,934,009	866,033	17.55	2,685,895	1.837
Kentucky.....	5	5	13,400	3,818,209	763,186	19.99	24,915,946	.153
Kansas.....	4	6	4,642	1,174,980	241,219	20.53	9,315,339	.126
New York.....	7	6	2,122	181,262	33,116	18.27	68,154	2.659
Colorado.....								
	750	886	902,385	217,884,104	40,188,956	18.45	429,287,797	.508

The production of gasoline from natural gas by compression and vacuum methods and by the absorption method for the years 1916 and 1917 is shown in Tables 2 and 3. The tables show that the quantity of gas treated in 1917 was more than double that of 1916, and that most of this increase was from gas treated in absorption plants.

TABLE 2.—*Production of gasoline from natural gas in 1916 by principal methods of manufacture.^a*

Gasoline produced by compression and by vacuum methods.

State.	Plants.		Gasoline produced.			Gas used.	
	Num- ber.	Daily capacity.	Quantity.	Value.	Price per gallon.	Estimated quantity.	Average yield in gasoline per M cubic feet.
		<i>Gallons.</i>	<i>Gallons.</i>		<i>Cents.</i>	<i>M. cubic ft.</i>	<i>Gallons.</i>
Oklahoma.....	104	215,377	45,827,325	\$5,471,307	11.94	14,018,757	3.269
West Virginia.....	135	39,276	9,289,624	1,642,031	17.67	3,550,523	2.616
Pennsylvania.....	185	30,287	6,722,370	1,216,717	18.10	2,693,215	2.496
Louisiana.....	7	10,661	213,159	269,564	12.76	907,153	2.329
Texas.....	4	6,688	1,292,811	201,023	15.55	948,485	1.363
New York.....	5						
Colorado.....	1	1,025	249,055	40,243	16.17	102,819	2.422
California.....	24						
Ohio.....	53						
Illinois.....	29	72,251	19,428,417	2,652,776	18.65	14,492,463	
Kentucky.....	3						
Kansas.....	2						
	550	375,565	84,922,787	11,493,701	14.53	36,713,415	

Gasoline produced by absorption methods.^b

West Virginia.....	14	59,383	9,475,432	1,383,262	14.60	101,114,013	0.094
Pennsylvania.....	10	13,200	2,992,556	509,456	17.02	35,797,406	.081
Oklahoma.....	12	17,700	2,532,277	393,838	15.55	10,730,697	.236
California.....	2						
Kentucky.....	2						
Illinois.....	3	26,600	3,569,637	550,891	15.43	24,349,492	
Ohio.....	2						
Kansas.....	1						
	46	119,883	18,569,902	2,837,447	15.28	171,991,608	
Grand total.....	296	495,448	193,492,689	14,331,148	13.85	208,705,023	.496

^a Mineral Resources of United States for 1916, U. S. Geol. Survey, 1917, pt. 2, p. 650.^b Includes drips.TABLE 3.—*Production of gasoline from natural gas in 1917 by principal methods of manufacture.^a*

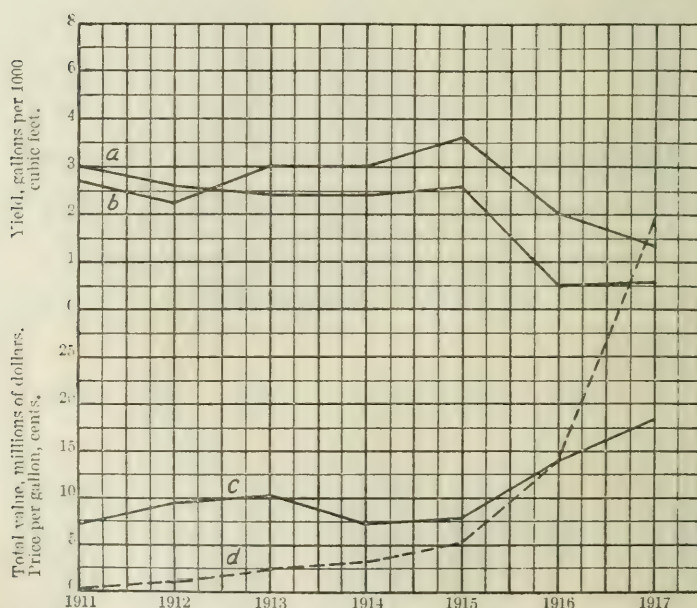
Gasoline produced by compression and by vacuum pumps.

State.	Plants.		Gasoline produced.			Gas used.	
	Num- ber.	Daily capacity.	Quantity.	Value.	Price per gallon.	Estimated volume.	Average yield of gasoline per M cubic feet.
		<i>Gallons.</i>	<i>Gallons.</i>		<i>Cents.</i>	<i>M. cubic ft.</i>	<i>Gallons.</i>
Oklahoma.....	207	456,632	108,728,213	\$20,321,067	18.68	36,399,280	2.987
California.....	40	82,092	23,478,521	3,637,827	15.49	27,477,443	.854
West Virginia.....	159	44,348	12,276,784	2,211,494	18.01	4,845,648	2.534
Pennsylvania.....	234	32,564	9,011,199	1,792,430	19.89	3,572,356	2.522
Louisiana.....	18	17,915	4,459,920	719,758	16.14	1,558,346	2.862
Illinois.....	54	15,392	4,268,158	756,344	17.72	2,020,044	2.113
Texas.....	8	10,900	3,942,337	664,543	16.86	2,666,983	1.478
Ohio.....	54	8,337	2,331,498	423,106	18.15	836,639	2.787
New York.....	5						
Kansas.....	1	3,322	369,925	70,361	19.02	150,784	2.453
Kentucky.....	3						
Colorado.....	1						
	784	671,502	168,866,555	30,596,930	18.12	79,527,523	2.125

^a Figures supplied by United States Geological Survey.

TABLE 3.—*Production of gasoline from natural gas in 1917, etc.*—Continued.Gasoline produced by absorption.^a

State.	Plants.		Gasoline produced.			Gas used.	
	Num- ber.	Daily capacity.	Quantity.	Value.	Price per gallon.	Estimated volume.	Average yield of gasoline per M cubic feet.
		<i>Gallons.</i>	<i>Gallons.</i>		<i>Cents.</i>	<i>M. cubic ft.</i>	<i>Gallons.</i>
West Virginia.....	23	91,315	20,391,863	\$4,300,319	21.09	162,925,703	0.125
Oklahoma.....	27	35,804	6,395,211	1,220,838	19.09	48,320,661	.132
California.....	9	17,669	5,339,083	800,195	14.99	17,873,804	.299
Pennsylvania.....	17	26,600	4,815,051	985,668	20.47	45,914,700	.105
Kentucky <i>a</i>	2	<i>b</i> 13,000	3,725,893	745,210	20.00	24,871,590	.150
Ohio.....	7	16,800	3,108,062	628,270	20.21	29,225,502	.106
Texas <i>c</i>	3	21,650	2,978,068	484,898	16.28	10,010,233	.238
Kansas.....	5	3,842	1,071,633	220,550	20.58	9,274,289	.116
Illinois <i>a</i>	1	2,000	665,851	109,689	16.47	665,851	1.000
Louisiana <i>a</i>	2	2,203	519,834	94,989	18.27	675,165	.770
New York <i>d</i>			7,000	1,400	20.00	2,776	
Colorado.....							
	102	230,883	49,017,549	9,592,026	19.57	349,760,274	.140
Grand total.....	886	902,385	217,884,104	40,188,956	18.45	429,287,797	.508

^a Includes drip gasoline.^b Includes gasoline produced in Kentucky from West Virginia gas.^c Includes some gasoline produced by compression.^d Drips only.FIGURE 1.—Curves showing yield of gasoline per 1,000 cubic feet of natural gas treated and value of gasoline produced, 1911-1917. Curve *a*, yield in United States; curve *b*, yield in Oklahoma; curve *c*, price of gasoline in United States in cents per gallon; curve *d*, total value of gasoline from natural gas in United States in millions of dollars.

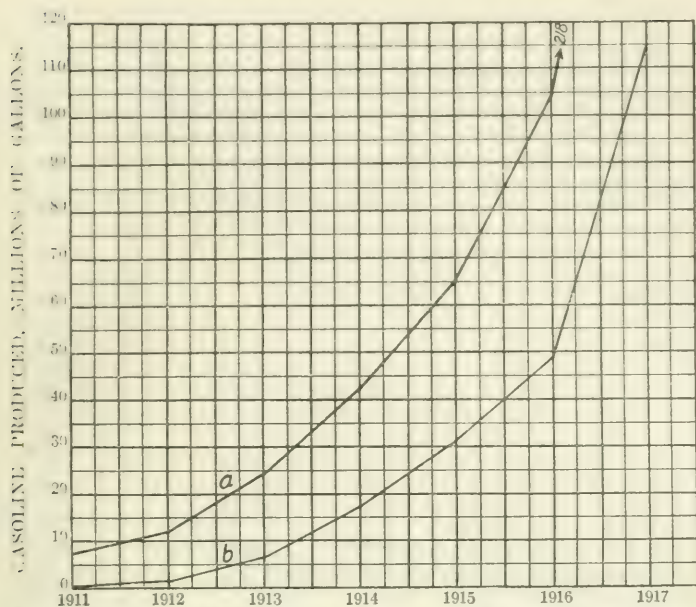


FIGURE 2.—Curves showing annual production of gasoline from natural gas in United States (curve *a*), and in Oklahoma (curve *b*), for the years 1911 to 1917, in millions of gallons.

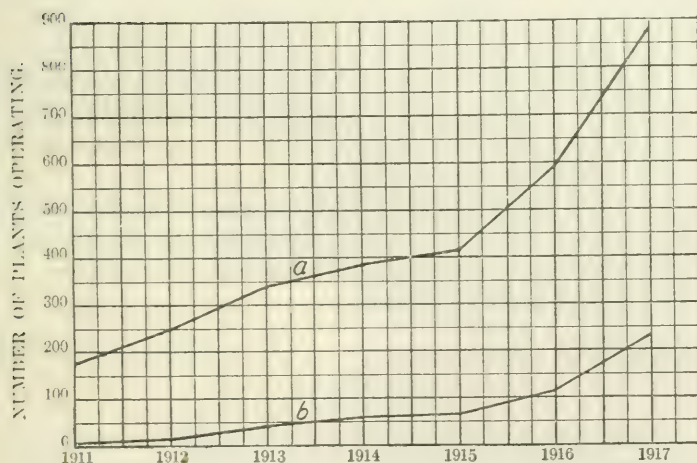


FIGURE 3.—Curves showing number of plants treating natural gas for gasoline in United States (curve *a*), and in Oklahoma (curve *b*), 1911-1917.

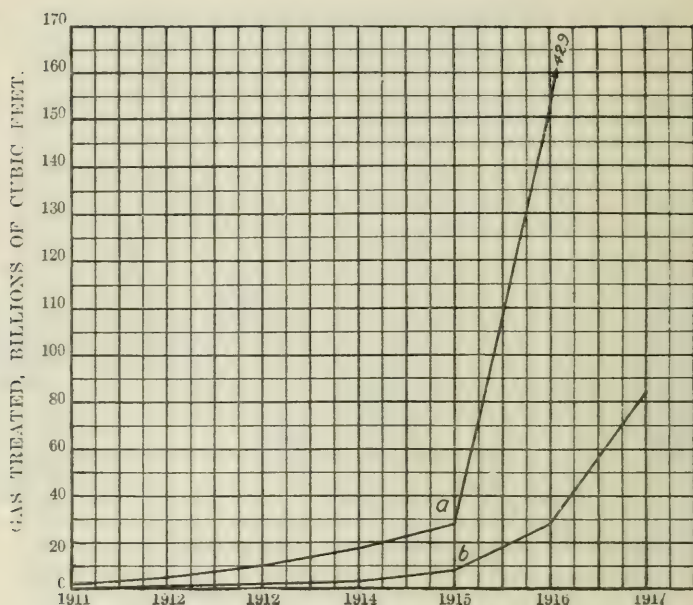


FIGURE 4.—Curves showing quantity of natural gas treated in United States (curve *a*), and in Oklahoma (curve *b*), 1911–1917.

The curves of figures 1, 2, 3, and 4 show graphically the output of gasoline from natural gas since 1910. In the years 1916 and 1917 construction was exceedingly active, many improvements being made in both compression and absorption plants. The output of gasoline from natural gas in Oklahoma in July, 1918, was probably more than 300,000 gallons a day, and in California 75,000 gallons a day from the 30 plants in operation. Eastern as well as western districts will undoubtedly show a steady increase in the production of gasoline from gas, because of the larger volume of gas being treated and the increased efficiency of the plants.

From what he has seen in the various fields, the writer thinks that the number of new plants in 1918 will be less than the number built in 1917, for the ratio between gas production and number of plants has become more nearly equalized.

CHARACTER OF NATURAL GAS TREATED BY ABSORPTION.

The first absorption plants treating natural gas were built only for the treatment of lean gases at high pressure and commonly were placed on the gas transmission lines after the gas had been compressed and passed through the cooling coils usually employed in gas pumping. The coils are used to remove the heat generated by com-

pression and to precipitate and collect from the gas as much as possible of the condensable vapors. Otherwise these vapors would cause rapid deterioration of rubber gaskets, which are used on pipe lines connected by couplings, and would entail additional expense through the construction and maintenance of a large number of pipe-line drips. In commercial gas pumping an absorption plant becomes a drying equipment that is of enough value for this purpose alone to warrant installation. In fact, drying the gas was one of the primary incentives in the development of absorption processes.

The gas being treated by large commercial gas companies in the eastern United States usually originates in gas fields that yield no oil, the gas being known as high-pressure "dry" gas. There are, however, in the East a few compression gasoline companies that after extracting as much condensate as possible, deliver the residual gas to the pipe lines of commercial gas companies, this gas receiving a second treatment by an absorption plant at the gas-pumping station.

In the Mid-Continent fields, besides gas from "dry" gas wells in gas pools, gas produced with the oil under high pressures (gushers) is separated from the oil in traps^a, admitted under its own pressure to the pipe lines of gas companies, and treated by absorption at the first pumping station through which it passes. Large quantities of such gas have carried 0.28 gallon of condensable vapor per 1,000 cubic feet, even when the pressure ranged between 300 and 500 pounds at the casing head. For such gas the percentage of condensable vapors carried invariably increases as the pressure drops.

In both the Mid-Continent and California fields the gas originating in oil wells at all pressures and vacuums is now being treated successfully by the absorption process; much of the gas contains quantities of vapor too small for treatment by compression alone. Practice seems to indicate that natural gas containing three-fourths of a gallon of gasoline per 1,000 cubic feet of gas is the driest gas yielding profitable results by compression, whereas absorption is used successfully for gas yielding from less than one pint to three and one-half gallons per 1,000 cubic feet, and also for uncondensed still vapors in refineries and topping plants and the vapors rising from flow tanks and storage tanks, as well as the residue gases discharged from casing-head gasoline plants.

In the study of both the compression and absorption processes in the various fields of the United States the writer found marked differences in the characteristics of the condensate recovered from gases yielding equal quantities of gasoline. This variation seems to depend on the proportion of each of the hydrocarbons in the gas; its existence is proved by the varying characteristics of the conden-

^a Hamilton, W. R., Traps for separating gas at oil wells: Tech. Paper 209, 1918, 86 pp.

sates produced as well as by the varying quantities obtained at the different pressures and temperatures at which the condensable vapors precipitate. Unfortunately, no method of analysis has been devised by which the percentages of the different condensable hydrocarbon members in natural gas can be even approximately estimated.

It seems that the character of the oil with which gas is, or has been, associated and the factors developed and used in compression plants would afford a good indication of the character of the gas and would indicate roughly the treatment necessary to obtain the desired quality of product by absorption.

PHYSICAL LAWS CONTROLLING ABSORPTION OF GASES IN LIQUIDS.

Inasmuch as the physical laws of gases apply closely to the absorption process, the more important are given here:

Henry's law is as follows: "The weight of any gas absorbed in the unit volume of a liquid, at any pressure, will be equal to the weight absorbed in that volume at one atmosphere pressure, times that pressure (in atmospheres)." This statement of the law presupposes that the temperatures are always equal. The coefficient of absorption of a liquid equals the volume of gas (at 0° C., 32° F.), which is absorbed in the unit of volume of a liquid at one atmosphere pressure. To illustrate how the absorption of gases by liquids varies with temperature the following example is given: Water absorbs 0.0498 volume of oxygen at 0° C. (32° F.) and 0.0244 volume at 35° C. (95° F.); at the boiling point 100° C. (212° F.) practically no oxygen will be absorbed or remain in solution.

Dalton's law of partial pressures is as follows: "Every portion of a mass of gas in a vessel contributes to the pressure against the sides of a vessel the same amount that it would have exerted by itself had no other gas been present."

Partial pressures have direct effects in the absorbing action in the towers, in the condensing of the distilled vapors, and in the separating of the gasoline from the oil in the still. As partial pressures affect practically all of the major functions of absorption operations, plant designers should completely understand the physical laws involved.

VAPOR PRESSURES.

When water is brought into a space that it does not fill, evaporation takes place until either all the water has been converted into vapor or the pressure of the water vapor has reached a certain definite limit, and a state of equilibrium exists between water vapor and liquid water. The limit of vapor pressure varies with the temperature and

is entirely independent of the size and shape of the vessel or the relative volume of the liquid or of the water vapor. The pressure at which the water vapor is in equilibrium with the liquid water is called the vapor pressure of the liquid.

These laws help to explain the absorption process but can not be mathematically applied to the problems met in plant designing except in a general way, because it is impossible to learn the percentages of the many hydrocarbon compounds that constitute the gas, and therefore the partial pressure of each at a given pressure, or to know the absorption coefficient of the absorbing medium for each of the fractions of condensable vapor, or the temperatures that will be developed in the plant at different seasons.

These facts explain why the many plants installed were designed in accord with results of experimental tests and small units operated as nearly as possible under plant conditions.

FACTORS CONTROLLING PLANT DESIGN.

The controlling factors of plant design are the pressures, temperatures and gasoline content of the gas to be treated and the time and intimacy of contact between the gas and the absorbing medium necessary to absorb the gasoline fractions that are at present commercially valuable.

PRESSURE.

Pressure affects the absorption process mechanically and physically. Mechanically it determines the weight and strength of materials used for pipe lines, towers, traps, and valves. Physically, it controls the actual volumes of gas, and thereby affects the speed of gas flow or flow velocity and is a factor in determining the percentage of saturation to which the absorption oil may be raised while removing the maximum quantities of condensate, that is, the quantity of oil to be circulated per 1,000 cubic feet of gas.

TEMPERATURE.

The temperatures of gas and oil during treatment affect gas volume, percentage of saturation, extraction efficiency, and also bear directly upon the character of hydrocarbons removed, because of the rise in vapor pressure of the condensable members with higher temperatures.

GASOLINE CONTENT.

The gasoline content of the gas being treated, together with the temperature and pressure of the gas and oil and the time of treatment, will determine the quantities of oil to be circulated.

CONTACT OF GAS AND OIL.

The intimacy and duration of contact between the oil and the gas must be regulated by the height of towers used as absorbers, and by the system of baffles together with the other factors controlling plant design in order to expose as large a surface of oil as is possible without too great constriction of the cross-sectional area of the tower.

HORIZONTAL ABSORBERS WHERE INSTALLED BEING REPLACED BY VERTICAL UNITS.

Although horizontal absorbers have been used at many plants and are at present included in the designs of some plants under construction, the trend of development is toward vertical units. This trend was so evident at the plants studied by the writer that horizontal types of absorbers are not included in the general discussion presented on the pages following. Many operators are rebuilding plants that originally had absorbers of the horizontal types, and are installing vertical units instead. The reasons given for this change are the difficulty of exposing large surfaces of oil to the gas being treated, excessive loss of pressure through friction in the treating units, and the low efficiency of extraction.

TESTING NATURAL GAS FOR GASOLINE CONTENT.

The methods of testing natural gas for gasoline have been described in Bureau of Mines publications^a and many articles on the subject have been published in the technical press. Only such methods as are not already well known and understood and are of particular interest and use in connection with absorption practice are given here.

LINE-DRIP MEASUREMENTS.

A company pumping between 30 and 40 million cubic feet of gas a day, using the ordinary cooling coils after compression, made tests preliminary to the designing of an absorption plant and found that 4,600 gallons of condensate were being blown from the

^a Burrell, G. A., Biddison, P. M., and Oberfell, G. G., Extraction of natural gas by absorption methods: Bull. 120, Bureau of Mines, 1917, 71 pp.; Dykema, W. P., Recovery of gasoline from natural gas by compression and refrigeration: Bull. 151, Bureau of Mines, 1917, 151 pp.; Burrell, G. A., Seibert, F. M., and Oberfell, G. G., The condensation of gasoline from natural gas: Bull. 88, Bureau of Mines, 1915, 106 pp.; Burrell, G. A., and Jones, G. W., Methods of testing natural gas for gasoline content: Tech. Paper 87, Bureau of Mines, 1916, 27 pp.; Calvert, W. R., A preliminary report on the utilization of petroleum and natural gas in Wyoming, with a discussion of the suitability of natural gas for making gasoline, by G. A. Burrell: Tech. Paper 57, Bureau of Mines, 1913, 23 pp.

line drips and wasted in one day. This single test proved the advisability of building a plant. The test was made during the coldest part of the year when condensation in the pipe lines was at a maximum. However, the results are reliable, as they indicate the minimum quantity of gasoline that an absorption plant would be able to produce at all periods of the year. The proposed plant was built and it now produces between two and three times the amount of condensate recovered during the drip measurements.

The tests described were made on pipe lines conveying gas under high pressure. The same method may be used for lines carrying gas under partial vacuum, but the percentage of condensable content will be much lower on account of the reduced pressure. The usual arrangement of piping for a drip on a vacuum line shown in figure 5 is self-explanatory. Mr. G. L. Goodwin says that from his experience, "it is always advisable to connect an equalizing line from

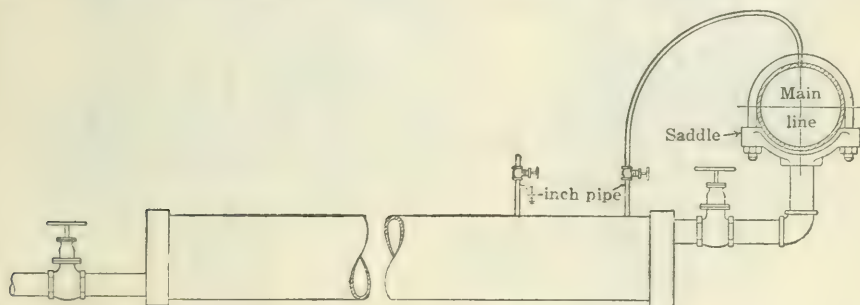


FIGURE 5.—Construction of line drip.

the highest point on the receiver to the top of the gas main line, as this greatly increases the efficiency of the drip collector."

The drips are always placed at low points in pipe lines and are built of standard pipe and fittings. A 2-inch pipe carries the condensed liquid through a valve and into a storage pipe made of one, two, or three lengths of large (6, 8, or 10-inch) pipe screwed together to form an accumulator or reservoir. This storage pipe slopes so as to drain into the 2-inch discharge pipe placed at the lower end and fitted with a valve to allow the liquid to be blown out.

TYPES OF TESTERS USED.

Numerous testing devices have been developed by the chemists and engineers of the natural-gas gasoline industry. They may be divided into two classes, those for lean gas, and those for rich gas, but no line of demarcation can be drawn, as by proper manipulation many of them may be used for gas of any gasoline content.

TESTERS USED IN PRACTICE.

SINGLE-CELL TESTERS.

The type of testing apparatus most often found in use is that designed by P. M. Biddison^a and described by G. A. Burrell as follows:

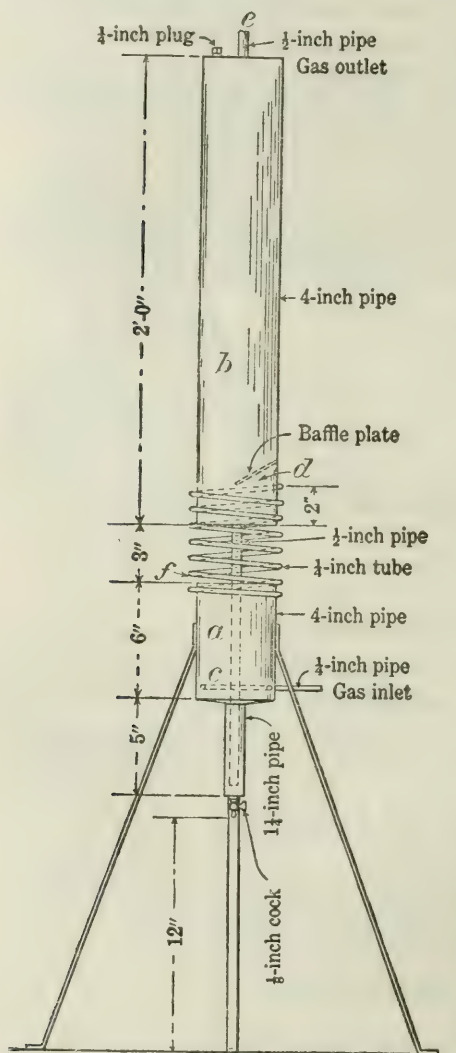


FIGURE 6.—Single-coil absorption tester.

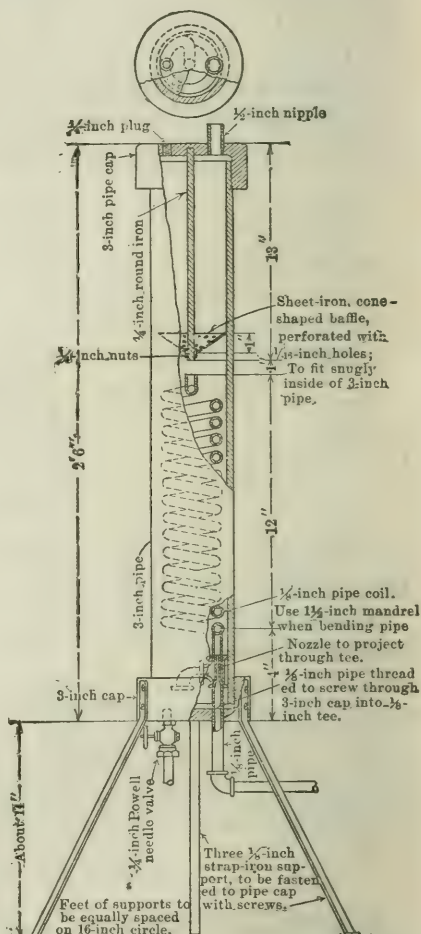
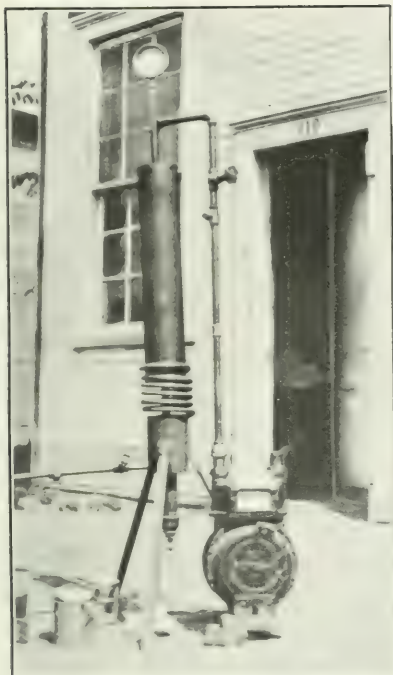


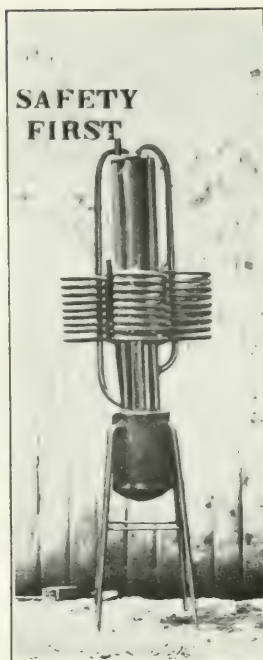
FIGURE 7.—Tester of induction type.

The absorber, shown in figure 6 and Plate I, A, which is built on the principle of a laboratory gas-washing bottle of the Friedric type, is of iron pipe thoroughly welded. It is about 3 feet high, and the two main barrels

^a Chief engineer, Ohio Fuel Supply Co., pipe-line department.



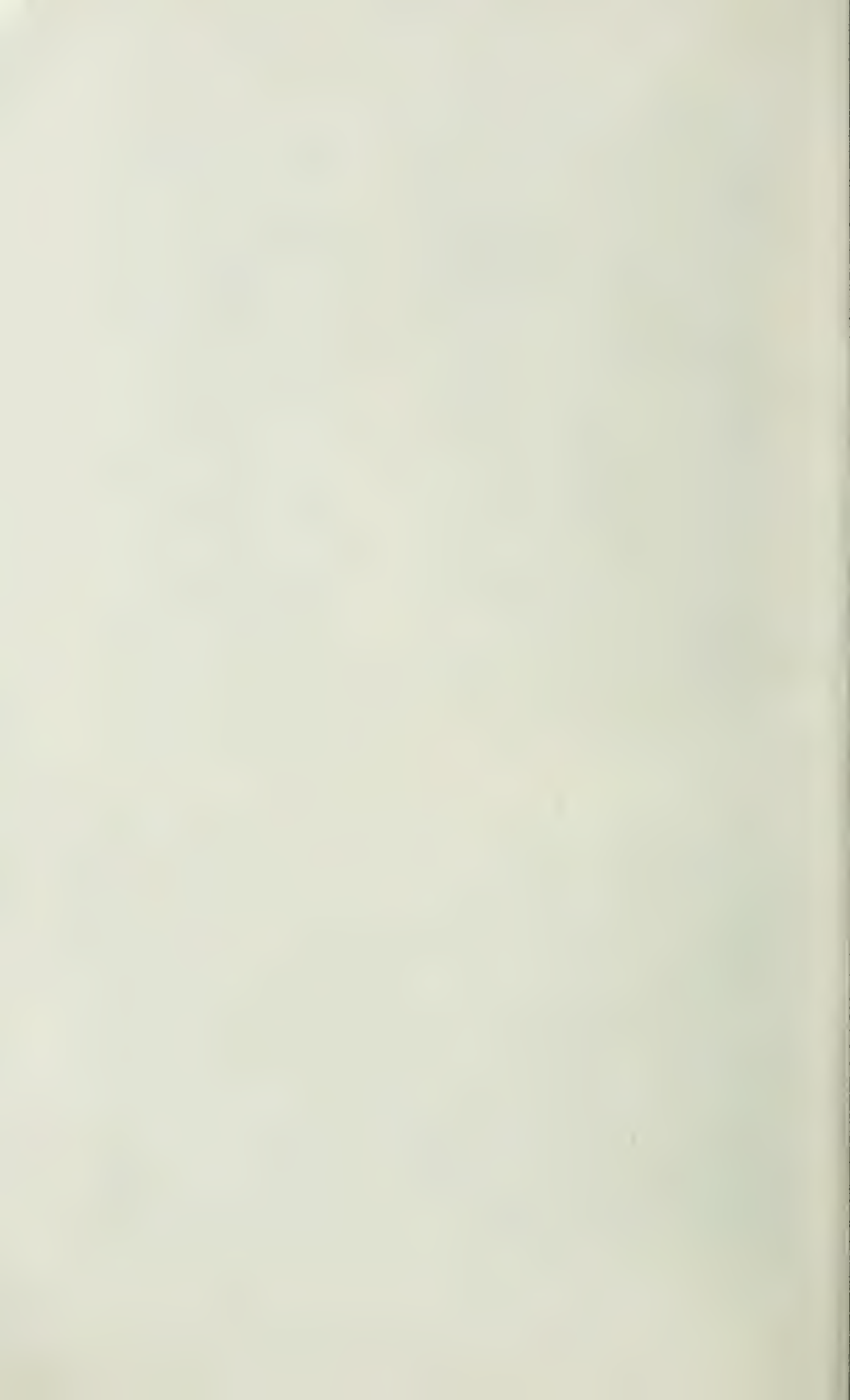
A. SINGLE-COIL ABSORPTION TESTER
SET UP FOR TEST.



B. QUADRUPLE-COIL, SINGLE-
CELL TESTER.



C. QUADRUPLE-COIL, FOUR-CELL TESTER.



a and *b* (fig. 6) are of 4-inch pipe. The entering gas bubbles up through the absorbing oil at *c* and passes through the coil of pipe *f* and into the part *d* and out at *e*. This apparatus was designed as a very efficient absorber, to show the maximum possible yield of gasoline from natural gas.

For making preliminary tests a single absorption unit of this type gives satisfactory results as long as the percentage of saturation is kept below 4 per cent and the gas is passed through the oil and tube slowly. When the amount of gas passed through allows the oil to become saturated to 6 or 7 per cent, the results of the test will be 15 to 25 per cent or more below the true value. Gas under atmospheric or low pressures, because of larger volume, should be passed through the unit more slowly than gas at high pressures, as time of contact is one of the factors controlling absorption. Figure 7 shows the detail of a single treatment tester in which a small nozzle on the pipe supplying the gas acts like an injector to force and mix the oil in the tubing coil. This type of absorption tester is usually termed an induction tester because of the mechanical principle involved.

In final testing, three, four, or five units of the single cell type are connected in series, the gas is passed through each in turn, the gasoline is extracted from the oil in each unit separately by distillation, and the total extraction is

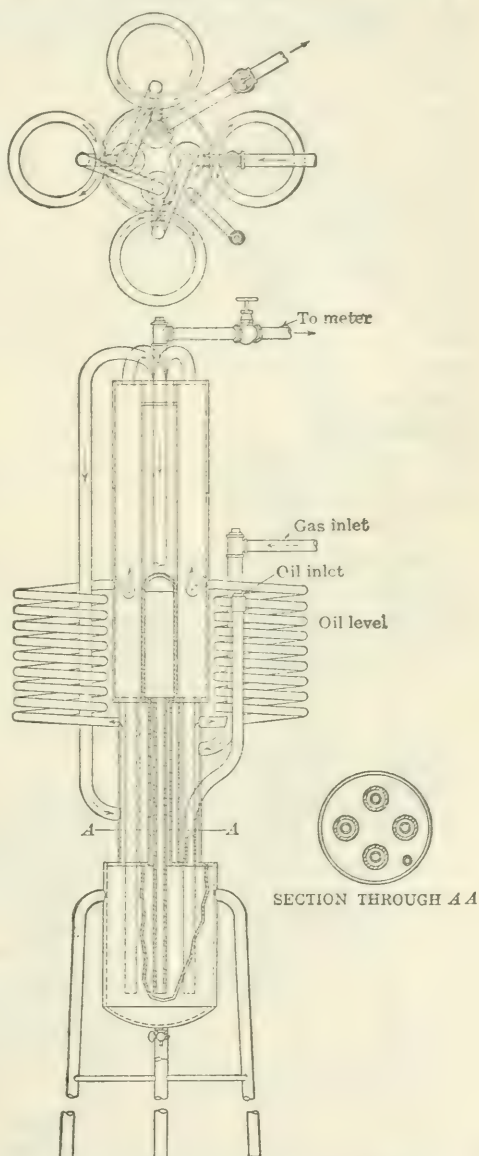


FIGURE 8.—Multiple-coil tester with single oil chamber.

computed. The oil in the last unit should show very small extraction or none at all. This proves the test.

A large company in Oklahoma uses four units of this type as a check on plant operation, tests being run once or twice weekly. The

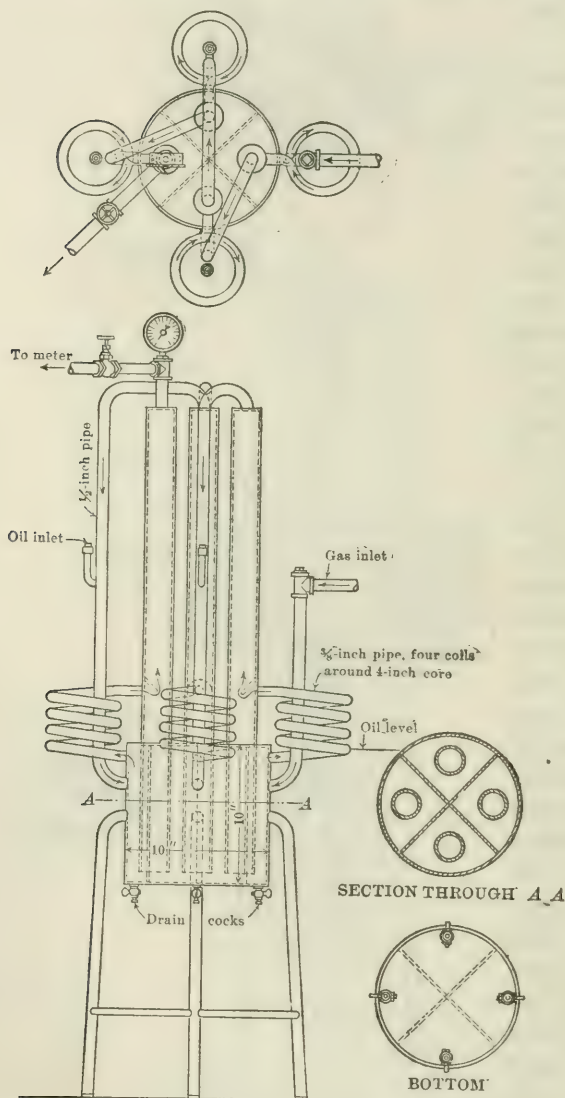
results are considered as 100 per cent extraction, and the daily plant efficiency is computed on that basis.

Mr. Biddison improved the original single cell, single coil tester by using multiple coils and larger quantities of absorbing oil and increases the number and the duration of the contacts between oil and gas. (Fig. 8, and Pl. I, B.)

The method of operation is essentially the same as that of the unit shown in figure 6, although the quantity of gas can be increased because of the large amount of oil used, which is three to five times as much as that in the bowl of the single coil type. Because of the successive contacts the flow velocity may be increased. This type

of tester is used on rich or lean gas at

FIGURE 9.—Multiple coil tester with quadruple cell chamber.



any pressure by varying the quantity of gas treated and the rate of gas flow. It gives the gas four treatments with the oil, uses only one oil charge and requires but one distilling to determine the total extraction.

MULTIPLE-CELL TESTERS.

A combination of the two types which is shown in figure 6 (single) and figure 8 (quadruple-coil single-cell tester) has been designed and used by Mr. J. D. Creveling, chief gasoline engineer of the Logan Natural Gas Co., Columbus, Ohio. Figure 9 and Plate I, C, show this type of tester. The bowl is divided into four compartments, each holding approximately 3,000 c. c. of absorption medium, and each filled through a short, upturned arm welded to the gas pipe that leads to each oil chamber.

When in use each chamber of the bowl is charged with an accurately measured quantity of absorption oil (approximately 3,000 c. c.), and the charging pipe is securely capped. The gas passes into the first section of the bowl, then upward through the first coil to the separating pipe chamber; the oil carried up with the gas descends to the bottom of the chamber from which it came, and the gas passes up and into the pipe leading to the second oil-filled chamber where the second contact with oil is obtained. The gas flows through each of the four chambers in turn and out at the top of the fourth separating pipe to the meter.

The oil is drained from each chamber, measured, tested for gravity, distilled separately, and the total extraction is computed. According to the rate of flow, gasoline content, the total quantity of gas treated, and some other small factors, the variation in the percentage of extraction in each of the four chambers will be as follows:

Gasoline absorbed in each chamber.

	Per cent.
First compartment-----	60 to 90
Second compartment-----	10 to 25
Third compartment-----	1 to 15
Fourth compartment-----	0 to 6.5

The controlling functions of the tester are shown in the tables below.

Controlling functions of quadruple tester.

Maximum rates of flow of gas, cubic feet per hour:	Pounds absolute pressure.
400-----	300
200-----	150
100-----	75
50-----	40
20-----	Atmospheric pressure.

Maximum gas capacity.

Gas, cubic feet:	Gasoline content, gallons per 1,000 cu. ft.
800-----	.125
400-----	.25
200-----	.50

Gas, cubic feet--Continued.

Gasoline content,
gallons per 1,000
cu. ft.

150	0.75
100	1.00
66	1.50
50	2.00
35	3.00
25	4.00

If the maximum quantities of gas are passed through the tester the oil in the fourth chamber will probably contain a small fraction of gasoline and should always be tested.

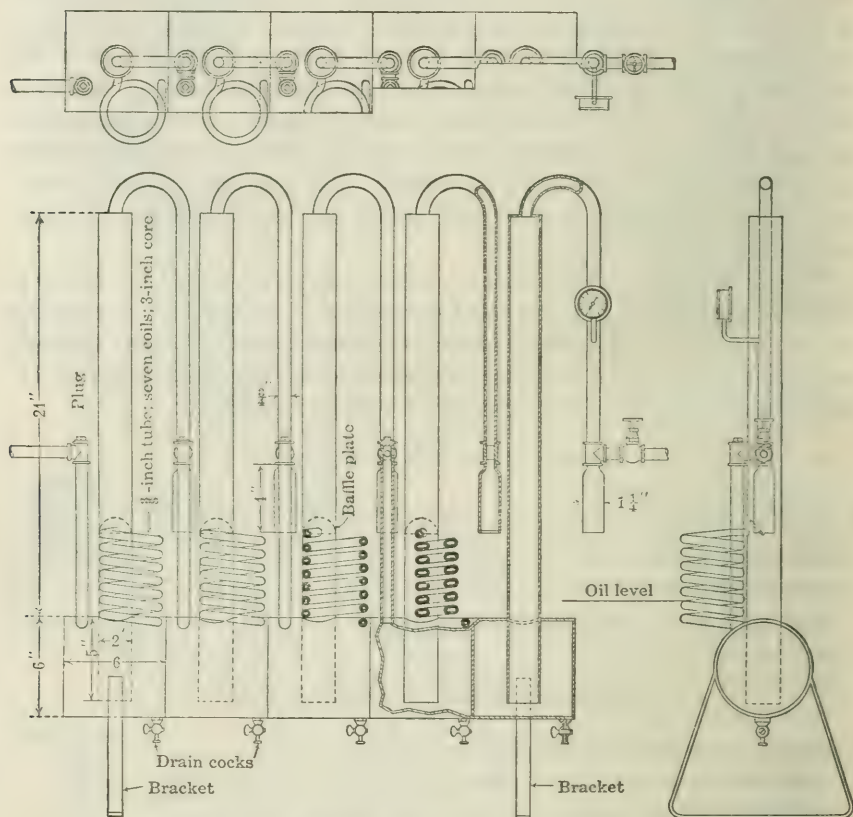
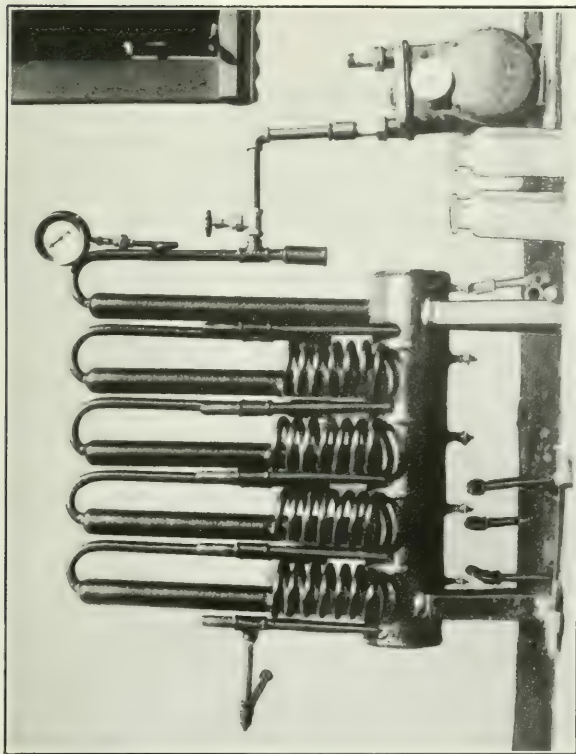
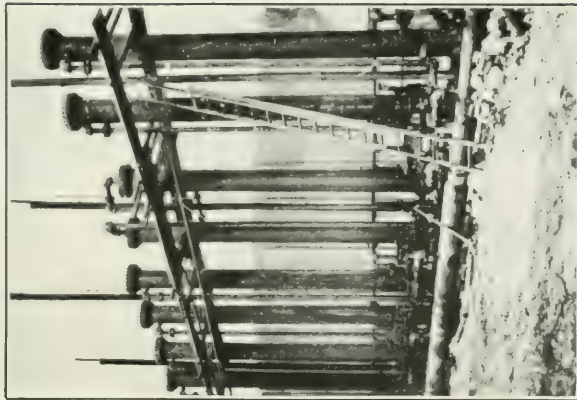


FIGURE 10.—Multiple tester used by Bureau of Mines.

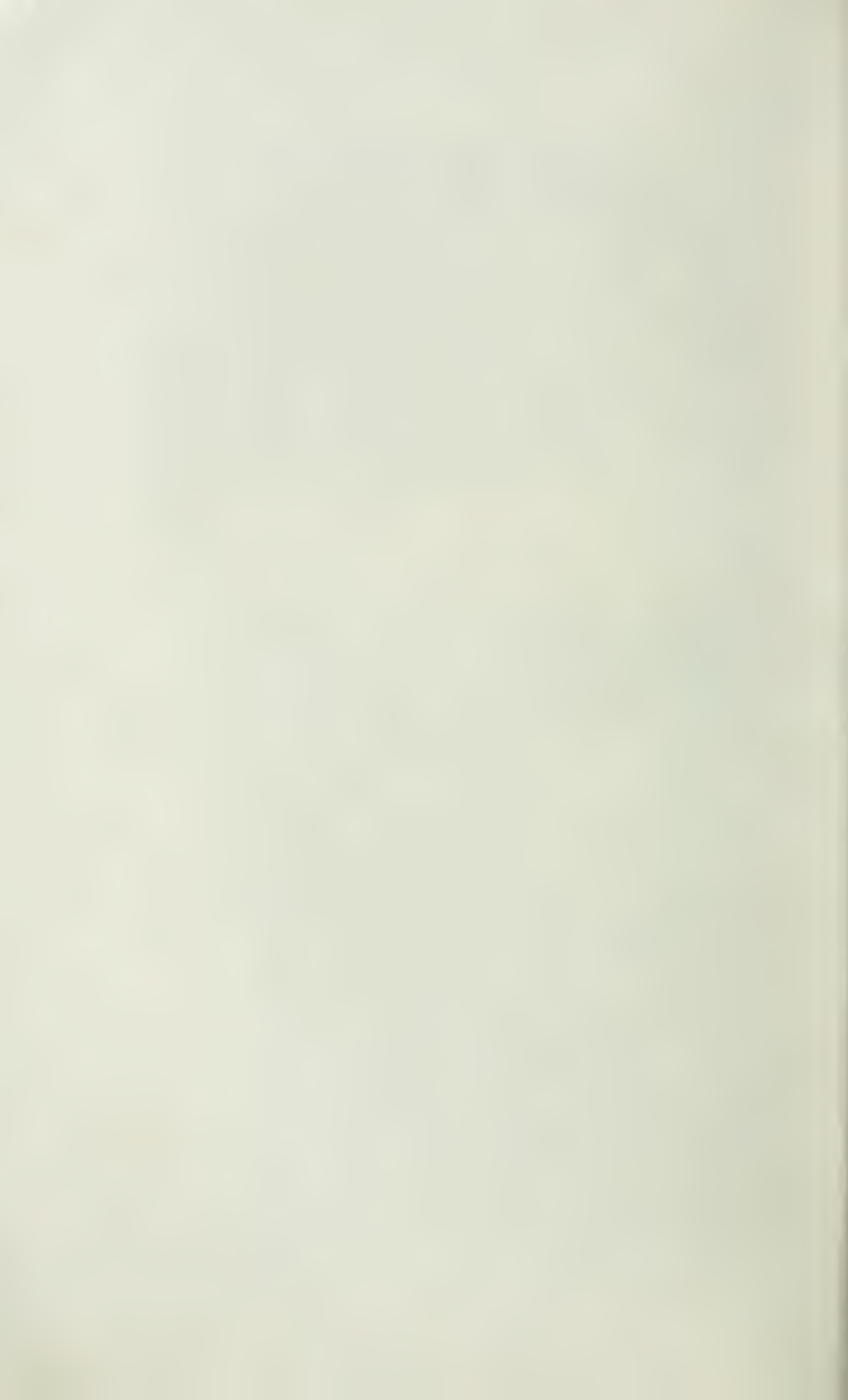
In figure 10 and Plate II, A, is shown an absorption tester designed by the writer to embody the most recent improvements; it provides multiple treatment in a rigid unit. Large gas companies give gas four or five treatments as a check on plant extraction. The gas is put through the tester under pressures and temperatures like



A. TESTER (SHOWN IN FIG. 10) IN OPERATION.



B. TOWERS 20 INCHES BY 25 FEET DESIGNED FOR CAPACITY OF 1,000,000 CUBIC FEET EACH, AT 100-POUND PRESSURE.



those in the plant proper. The oil in the last chamber is tested for gasoline but the chief purpose of testing is to check the extraction in the other chambers to prove that the extraction is maximum.

Although these types of testers, all based on the same principle, are most commonly used throughout the United States, there are other types whose value is indicated by their continued use. The autoclave tester is a type frequently used.

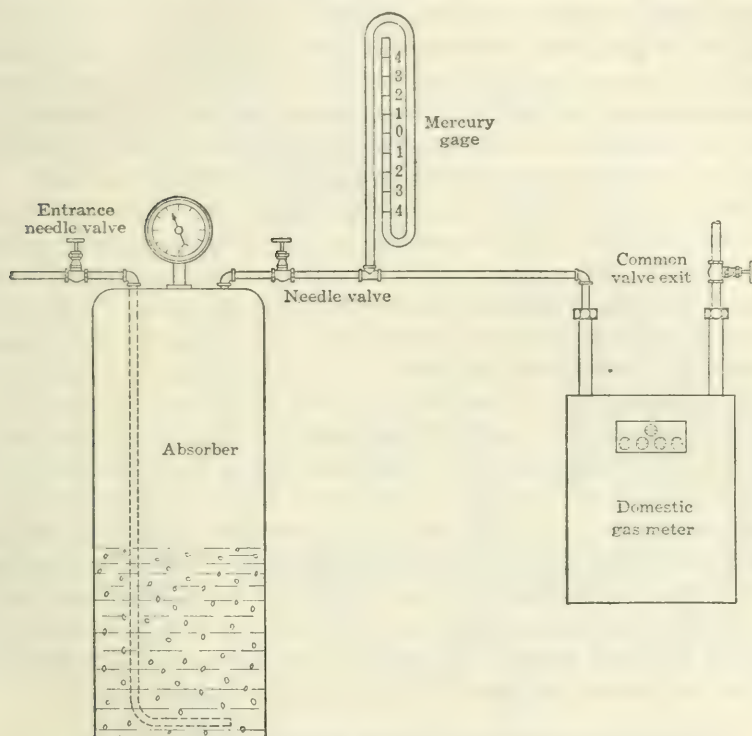


FIGURE 11.—Autoclave absorption tester.

AUTOCCLAVE ABSORPTION TESTER.

Figure 11, taken from California State Mining Bureau Bulletin 73,^a shows the tester used by a large California company. Two or more of these absorbers are often coupled in series in the same manner as those previously described, and for the same purpose. This tester treats both lean and rich gas. It is especially useful in tests with crude oil as an absorbent when low saturation and large quantities of oil are customary.

^a McLaughlin, R. P., First annual report of the State oil and gas supervisor of California for the fiscal year 1915-16: Cal. State Mining Bull. 73, 1917, p. 231.

THE CUBIC FOOT BOTTLE.

Oberfell^a has designed and used an absorption tester for gas of high gasoline content. A cylindrical tank of galvanized iron approximately one cubic foot in capacity is built, 10 inches in diameter and 24 inches in length, with slightly conical heads to allow drainage of oil. In the center of each head is welded or soldered a small ($\frac{1}{2}$ -inch) valve for charging and discharging both oil and gas. Although a tank or bottle of these dimensions will hold practically one cubic foot of gas under atmospheric pressure, in order to be accurate enough for testing gas it is carefully measured by the displacement and measurement of the air or gas contained and by weighing it empty and when full of distilled water. The bottles used by Oberfell are gaged carefully to the one-thousandth part of a cubic foot.

In testing gas the bottle is connected to the gas line at either the top or the bottom valve, depending on the specific gravity of the gas—at the top if the gas is lighter than air, and at the bottom if it is heavier. The gas is allowed to blow through the bottle for 30 to 60 minutes in order to remove all of the air. The valves are then closed, the gas line disconnected, and 850 c. c. of absorption oil are injected through either of the valves into the bottle containing the gas. The bottle and contents are violently agitated for a period of 20 minutes while the oil extracts all of the gasoline vapors from the gas. The gasoline content of the gas is computed from the results of distilling about 800 c. c. of the oil, using ice-cooled coils and collector to condense distilled-off vapors. Because of the extreme refinements required and the comparative simplicity and equal or greater accuracy of other methods of testing, it is doubtful if this method will be useful for final testing. In preliminary testing of rich gas it is practical because of its portability and light weight.

DISTILLING GASOLINE FROM ABSORPTION MEDIUM.

In completing the tests, the absorbed gasoline is separated from the absorption oil in fire stills or steam stills. The vaporized fractions pass through coils usually cooled by water and ice, and are condensed and discharged into a graduated vessel also cooled by water and ice. A steam still and coil of this type are shown in figure 12, taken from Bulletin 73, of the California State Mining Bureau.^b Many condensers do not depend on a flow of ice water as the vessel through which the vertical worm condenser passes is large enough to allow the ice to be added directly to the water surrounding the

^a Oberfell, G. G., Testing natural gas for gasoline: Jour. Ind. and Eng. Chem., vol. 10, March, 1918, p. 211.

^b McLaughlin, R. P., First annual report of the State gas and oil supervisor of California for the fiscal year 1915-16: Cal. State Mining Bull. 73, 1917, p. 232.

coil. This simplifies the operation and gives equally accurate results.^a

GENERAL USE OF TESTING APPARATUS.

Testing apparatus is now used not only to determine the quality of gas before a plant is designed, but also at large plants to show

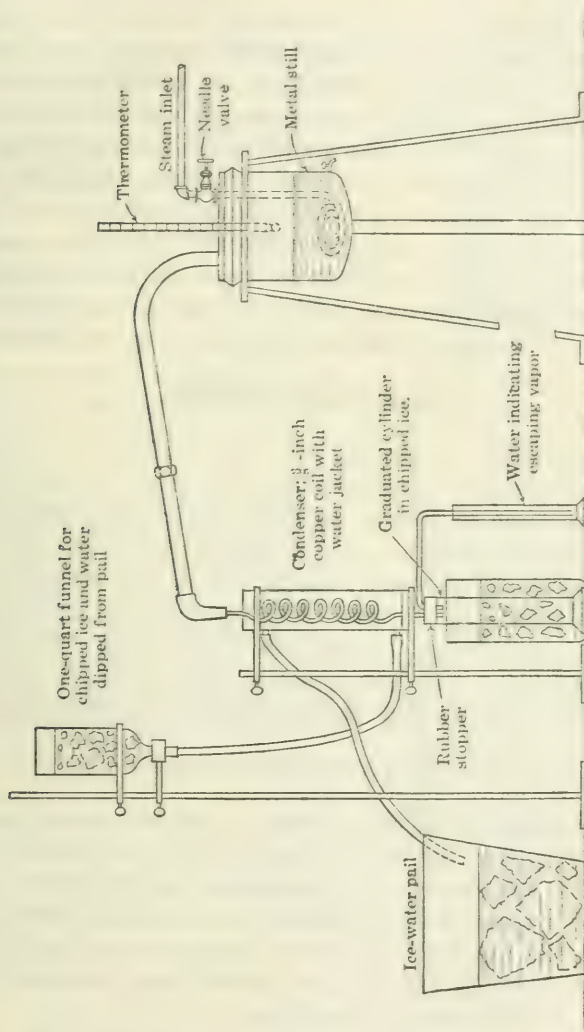


FIGURE 12. — Steam still and cooling apparatus.

from day to day the variations in the quantity of gasoline content and as a check on operation and efficiency. Such tests should be made frequently at all plants and the results filed with the records of plant pressures, production, and other essential information. In

^a See Dean, E. W., Motor gasoline; properties, laboratory methods of testing, and practical specifications: Tech. Paper 166, Bureau of Mines, 1917, p. 29.

some fields. Osage and Cushing for example, tests are made at regular intervals to determine the gasoline content of the dry gas, since royalties are paid on the gasoline content and figured on a 50 per cent extraction basis.

PLANT DESIGN AND OPERATION.

The greatest variation in plant design is found in the type, size, and construction of the towers, scrubbers, or driers, as they are variously called. In gasoline extraction, as in many other scrubber systems designed to work on the same principle, horizontal scrubbers have been found less efficient than the vertical or tower type. The horizontal installations in the Mid-Continent fields are not more than 75 per cent efficient and the average plant of this type not more than 60 per cent. As the horizontal units are being abandoned by operators, they will not be discussed in this paper.

Plants also differ widely in still construction and operation, design of heat interchanger, and vapor condensing and treatment.

ABSORPTION TOWERS.

Vertical absorbers or towers may be divided into two general classes—those in which comparatively lean gases are treated at high pressure, and those in which the richer gases are treated at lower pressures. No marked line can be drawn, as any gas, rich or lean, can be treated at any pressure with greater or less efficiency, depending on the mechanical features of the plant unit and the expense warranted by the total yield and life of the plant. As the industry at present treats the lean gases at high pressure and the rich gases at lower pressures, the classification holds for actual practice.

HIGH-PRESSURE TOWERS.

The largest volumes of gas treated by the absorption process are lean gas (0.1 to 0.3 gallons per 1,000 feet) from gas fields, which is pumped by commercial gas companies for distribution and use in cities and manufacturing plants. In order to reduce the size of pipe and the number and size of pumping stations, the gas is compressed to between 100 and 350 pounds in a pumping plant, and the gasoline is extracted by absorption.

High pressures affect tower design in two ways—first, by reducing the gas volume; and, second, by requiring heavy construction. Increased pressure allows towers of smaller cross section and, according to Henry's law, is a factor in determining the quantity of oil necessary to extract the vapors.

DIMENSIONS AND CAPACITIES OF HIGH-PRESSURE TOWERS.

Towers made of single lengths of pipe vary in outside diameter from 18 to 36 inches and in height from 18 to 40 feet. The thickness of metal is one-fourth to five-eighths inches, depending upon the diameter of the pipe and the working pressure.

Plate III, *A*, *B*, and Plate IV, *A*, show three views of a battery of absorption towers. Each unit is designed to treat a maximum of 6,000,000 cubic feet of gas daily at 275 pounds pressure. Figure 13 shows details of this type of tower. The double gas intake and discharge lines shown in Plate III, *B*, allow any or all of the towers to be cut into either of the two pipe lines into which the plant is pumping gas at different pressures.

Plate IV, *B*, shows towers of the same general construction as the one shown in detail in figure 13; the diameter is 30 inches outside and the height 32 feet, the pressure to be withstood is about the same. These towers are handling 7,000,000 cubic feet of gas a day, at a pressure between 225 and 275 pounds.

In comparison to these larger towers, Plate II, *B* (p. 20), shows eight towers 20 inches by 25 feet, each having a capacity of 1,000,000 cubic feet at 100 pounds, or 2,000,000 cubic feet at 200 pounds pressure. Figure 14 shows in detail the construction of towers similar in design and capacity, also the baffles in the form of a cartridge, mentioned under wood baffle construction. Plate V, *A* and *B*, shows 20-inch by 30-foot towers that handle from 150,000 to 200,000 cubic feet of $\frac{1}{2}$ gallon gas each per day, at 25 to 35 pounds pressure.

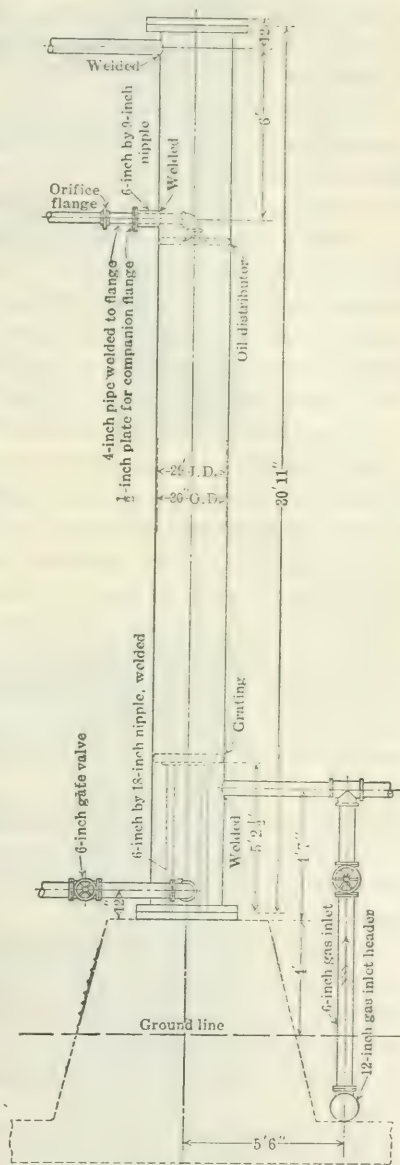


FIGURE 13.—Detail of construction of high-pressure tower.

FLOW VELOCITY OF GAS.

The diameters of towers vary, and also the pressures and volumes of gas at different plants; however, when the actual volumes of gas at the given pressures and the velocities of flow through the tower are computed, the velocity of gas through the towers is calculated to be from 30 to 75 feet a minute, disregarding the area reductions caused by baffling. The different systems of baffling, however, have "porosities"^a varying between 3 and 75 per cent that cause the actual flow velocities to increase to as much as 200 more feet a minute in some plants; this is far too rapid for good extractions.

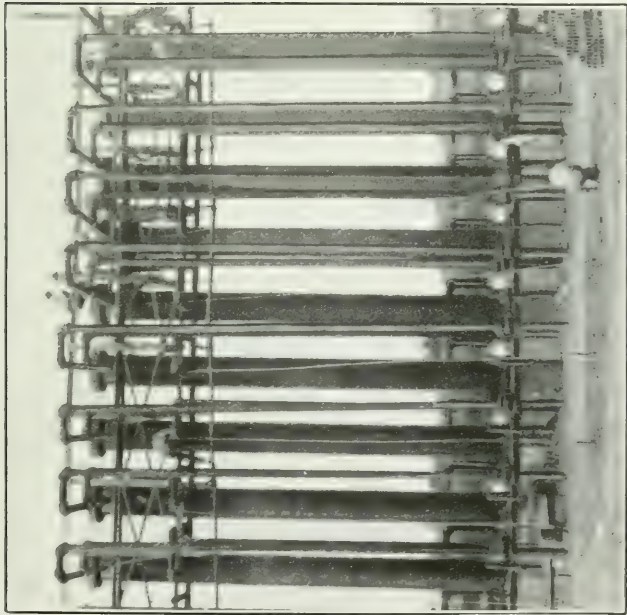
A company in the Mid-Continent field, using 30-inch towers 32 feet high and 200 pounds gas pressure puts seven million feet a day through each tower, using baffling with 50 per cent "porosity" that causes a flow velocity of 150 feet a minute in the baffled part, or 75 feet a minute in the open, or unbaffled part, of the tower. They find that higher velocities carry oil out of the towers.

The gas before leaving the tower through the outlet passes through a length either of open towers or of a series of baffles constructed to separate entrained oil from the gas. It is usual practice to place an oil trap or separator of some kind between the tower discharge and the gas main intake to induce a complete separation of oil and gas in an emergency, such as flooding, or excessive velocity of gas in the absorption tower, which will often carry oil over with it. Under normal conditions of running the open length of tower completely separates the oil and gas when the velocity of gas flow is not greater than 30 to 75 feet a minute in unbaffled parts of the tower. The extremes of flow velocity found in the plants visited were 30 feet a minute minimum, and 260 feet a minute maximum. At the latter plant oil was sometimes carried through the separating traps placed in the upper part of the tower and into the oil traps on the main gas-lines, and the extraction of gasoline from the gas was not satisfactory.

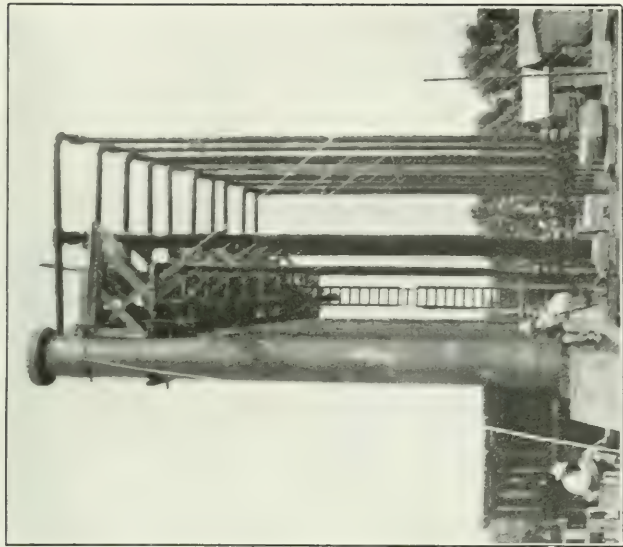
At the flow velocities given above any particle or molecule of gas passing through a tower will be in contact with the oil not over 50 seconds. In order to allow a great number of contacts, or contact of longer duration between gas or vapor particles and the oil, many engineers are studying results with towers of greater height.

One company is increasing its towers from 20 to 30 feet, and another, that has used 30-inch by 30-foot towers, plans to install 30 or 36 inches by 40-foot towers, claiming that by reducing the flow velocity and increasing the time of contact a greater extraction can

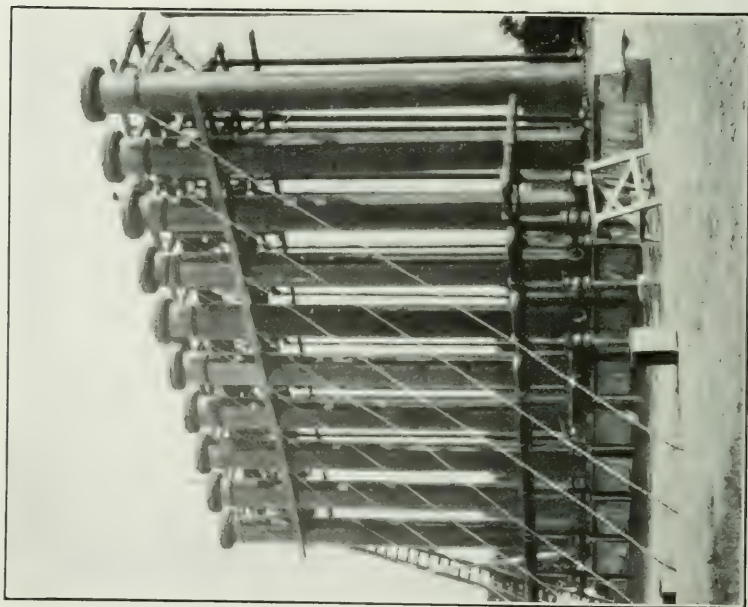
^a The expression porosity as here used refers to the ratio of the area of open space to that of the solid parts of the baffle.



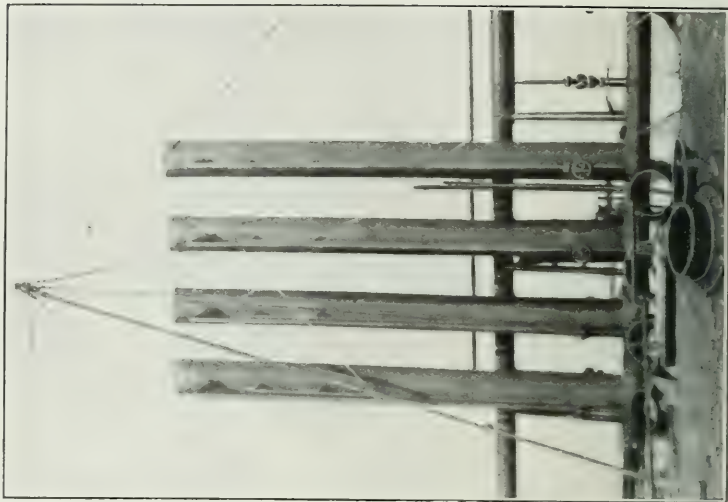
A. BATTERY OF ABSORPTION TOWERS. NOTE PILE OF BUILDING TILE IN FOREGROUND AT EXTREME RIGHT, USED AS TOWER FILLING OR BAFELING; ALSO NOTE OIL-DISCHARGE TRAPS AT FOOT OF EACH TOWER.



B. SAME BATTERY OF TOWERS, VIEWED FROM END. EACH TOWER IS 30 INCHES BY 30 FEET 11 INCHES; CAPACITY 6,000,000 CUBIC FEET OF GAS DAILY, AT 275-POUND PRESSURE.



A. GAS-INTAKE SIDE OF TOWERS SHOWN IN PLATE III.



B. TOWERS, 30 INCHES BY 32 FEET, IN COURSE OF CONSTRUCTION. DESIGNED FOR CAPACITY OF 7,000,000 CUBIC FEET EACH, AT 250 POUNDS.

be obtained and less oil circulated per 1,000 cubic feet of gas. As a result the boiler horsepower required will be less for both pumps and stills, and the recovery of gasoline will be greater. The total increase in the height of a tower can be used for baffling space, as the open portions of towers for intake and discharge of gas need not be increased. The addition of 10 feet to the height of a tower 30 feet high will increase by 50 per cent that portion in which the extraction is accomplished.

As the pressure at which gas is to be treated is usually fixed, the number of towers necessary to treat the gas will be controlled by the actual volume of gas at the given pressure, and the diameter of pipe chosen for tower construction.

In designing plants it is well to choose towers of such diameter as to require a number rather than one tower of cross-section area large enough to treat all of the gas. As in the practice of extracting gasoline from gas by compression, the number of units should be such that if one unit is for any reason cut out, the number left in the gas circuit will for a short time, at least, be able to treat all of the gas without overtaxing their capacity or lowering the plant efficiency unduly. A designer in Oklahoma, having to treat daily an average of 6,000,000 feet of gas at 250 pounds pressure, put in three 20-inch towers rather than one 36-inch tower, although the latter would have had capacity enough for all of the gas at approximately the same flow velocity. Two 20-inch towers will handle all the gas by working at full capacity at maximum pressure. The third tower is to be used in parallel with the other two while the plant runs normally, but it is expected to pay for itself during breakdowns by treating gas that would be by-passed around the towers and the gasoline lost if only two towers were installed.

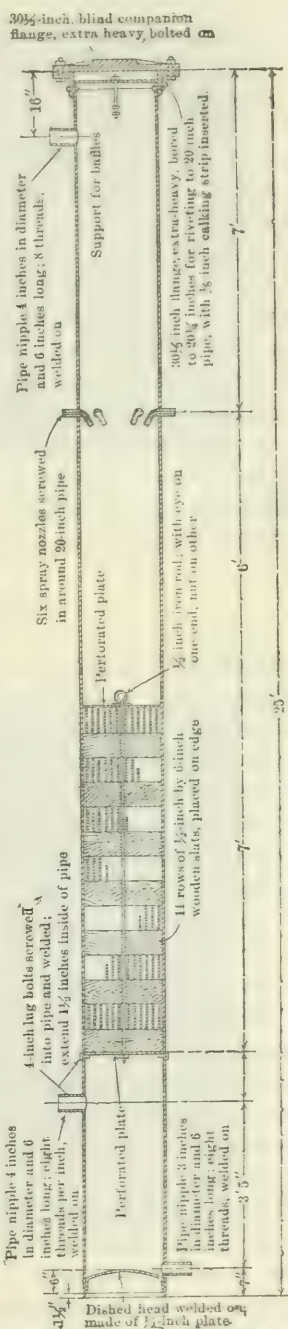


FIGURE 14.—Detail of high-pressure tower, 20 inches by 25 feet in size.

The largest welded towers of line pipe that were treating high-pressure gas were 36 inches in diameter, and the largest built-up tower was 12 feet in diameter. The latter was used in treating rich gas at less than 10 pounds pressure.

The height to which a tower must be built to yield the maximum economical extraction with the least oil, has not yet been determined, but as the present tendency is to increase this dimension in towers for high and for low pressure, the limit may soon be found. In the absorption process developed for scrubbing coke-oven gas the height limit is 75 feet.

Many methods of treatment have been devised, such as scrubbing the gas in sprays of oil before sending it to the usual towers, passing the gas through two or more towers, and bringing the oil and gas in contact in seven different units at different pressures or temperatures. As the form of single towers shown is simple, inexpensive, and perfect in counter-current flow treatment, it seems improbable that, except for changes in height, any other system of treatment equally efficient and simple in construction and operation will be invented for lean high-pressure gas.

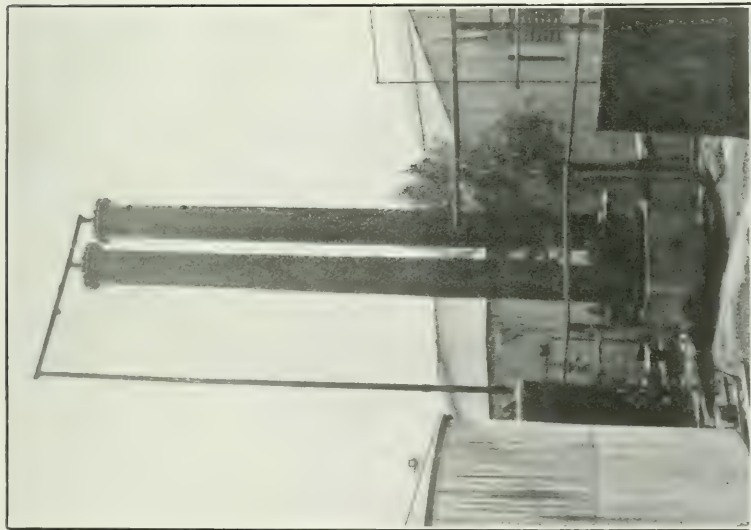
MECHANICAL AGITATION.

Machines to agitate oil in the presence of gas are being tested at present, and experimental plants of small capacity using such machines have made good extractions and consumed little power. It is too soon to predict to what ultimate use mechanical agitation may be put, but indications are that it will prove useful. The process will be thoroughly tested, particularly in connection with small quantities of rich gases and still vapors and with flow-tank and weathering-tank vapors.

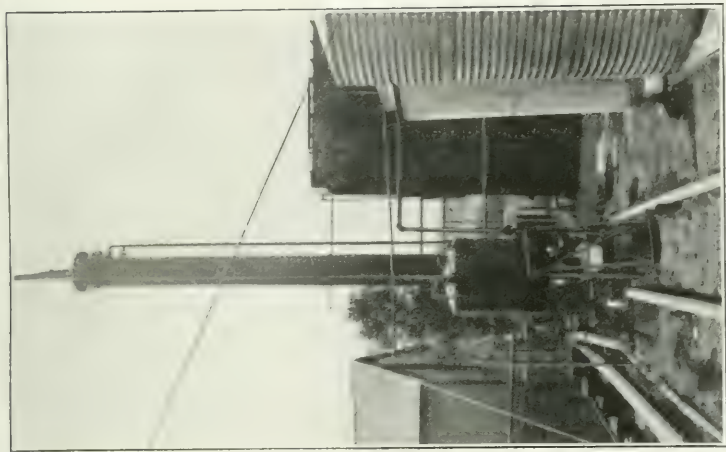
LOW-PRESSURE TOWERS.

The same principles hold true for low pressures (up to 30 pounds) as for high pressures; the important difference is the effect on tower construction. Because of the low pressures towers may be constructed of light boiler plates riveted together and, owing to the increased volume of gas, a greater cross-section area of tower is needed in order to maintain the minimum flow velocity and maximum time of treatment.

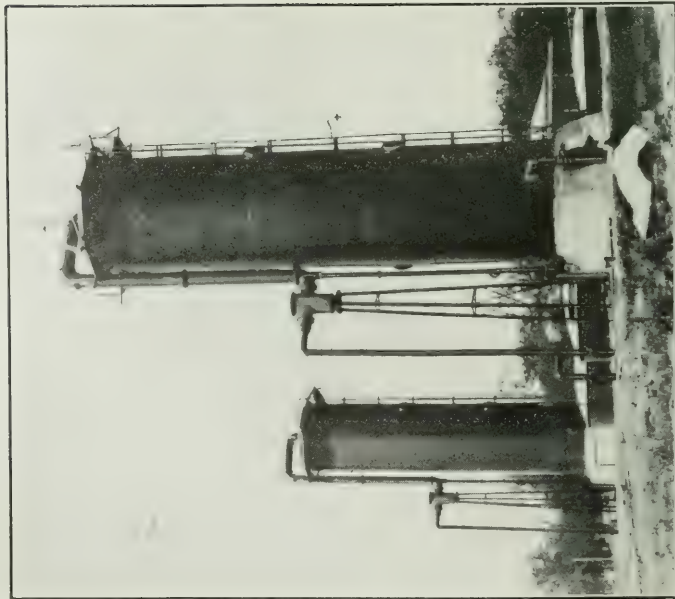
Plate VI (*A* and *B*) shows low-pressure towers built of light boiler plates riveted together, 12 feet in diameter by 48 feet high. The cross-section area is approximately 110 square feet, and the capacity in the unbaffled portions of the tower is 2,500,000 cubic feet of 2.5-gallon gas daily, with a flow velocity of about 30 feet a minute, at atmospheric to 5 pounds pressure. The towers are filled or baffled



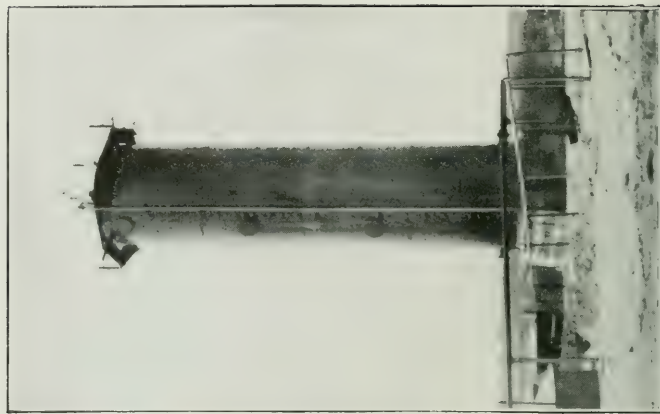
A. TOWERS, 20 INCHES BY 30 FEET. CAPACITY 150,000 TO 200,000 CUBIC FEET EACH, AT 25 TO 35 POUNDS.



B. SIDE VIEW OF SAME TOWERS SHOWING OIL INLET.



4. TOWERS, 12 BY 48 FEET; WORK AT ZERO TO 10-POUND PRESSURE, AVERAGE CAPACITY 2,500,000 CUBIC FEET EACH. NOTE TRAP ON GAS-DISCHARGE LINE.



B. ANOTHER VIEW OF SAME INSTALLATION.

with 1 by 4 inch boards set 1 inch apart in each grating, and one grating set on top of the other with its strips placed at a small angle to the one below. The gratings are set in 12-foot tiers, with open spaces of 2 feet above each tier. Plate VI, *B*, shows the manholes in the side of the tower entering the 2-foot open section above each of these tiers of baffles. The piping is so arranged that the two towers can be used either in series or parallel.

Multiple units of smaller diameters are also used for absorptions at the lower pressure. The towers in Plate VII, *A*, are 18 inches in diameter by 33 feet high, filled with cobbles about $2\frac{1}{2}$ inches in diameter. The pressure used is approximately two atmospheres, and the total quantity of gas is two to three million feet a day. When 3,000,000 feet are passing through the three towers at two atmospheres pressure, the flow velocity in the unbaffled portion of the tower is 190 feet a minute and in the baffled part (if the "porosity" is 50 per cent) the velocity will be twice that, or much higher than should be used in treating $\frac{1}{2}$ -gallon gas. Higher pressures, or more or larger towers, would overcome this difficulty. These towers are about the proper size to treat 250,000 feet of gas a day each at 25 pounds pressure.

After the gas has passed through the towers and traps and is completely separated from the oil, it is delivered into mains and distributed in the same manner as it was before the absorption or drying units were installed.

LOSS IN VOLUME AND HEATING VALUE OF GAS DUE TO ABSORPTION TREATMENT.

The loss in gas volume owing to the extraction of condensable fractions is represented, first, by the liquid products recovered and counted as net gasoline production, and, second, by the part of the gas that is carried from the towers as dissolved gas but can not be condensed after passing through the distilling process, or can not be held as liquid in the condensed still-vapors during subsequent handling and shipping. Of the first portion each gallon of product represents between 30 and 35 cubic feet of gas, or each gallon of condensate from 1,000 cubic feet reduces the original volume of the gas 3.5 per cent.

The second portion is more difficult to estimate, its volume depending on temperatures, pressures, and methods used at different plants as well as on the vapor tensions of the condensable fractions contained in the gas treated. In most plants this second portion is not to be computed as loss, as the vapors from still coils, accumulators, and weathering tanks are collected and used as fuel for power for the plant or are pumped back to the gas lines. The practice of

blowing into the air the gases from stills, weathering tanks, and coils or any other point is to be condemned as dangerous and wasteful.

As to the loss of heat units, through the extraction of the condensable vapors, Biddison^a has published the statement following:

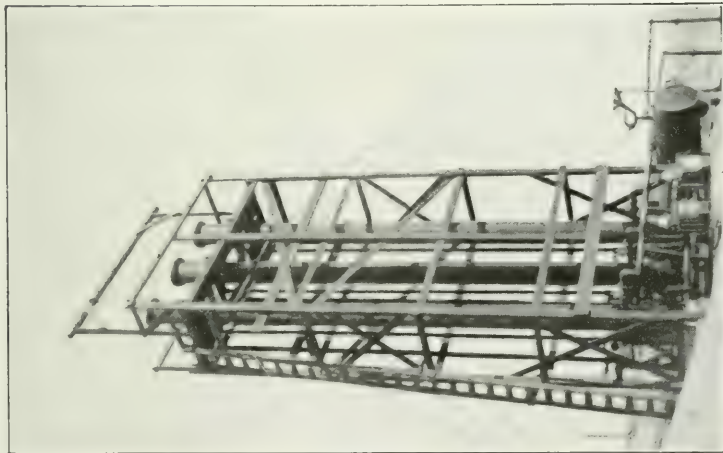
The reduction in heating value due to the recovery of the gasoline content can be closely estimated. Suppose a given gas has a gasoline content of 100 gallons per million feet of gas, or 0.0001 gallon per cubic foot of gas. The gasoline made by the absorption process will cause a shrinkage in volume of the gas treated, each gallon of gasoline being equal to about 35 feet of vapors. Then 0.0001 gallon of gasoline extracted from one cubic foot of gas would cause a shrinkage of 0.0001×35 , or 0.0035 cubic foot, leaving, out of each cubic foot treated, 0.9965 cubic feet available for marketing. Now, gasoline of the nature made by this process has a heating value of about 20,400 B. t. u. per pound and is about 80 Baumé gravity, or 5.549 pounds per gallon. The heating value per gallon is then $5.549 \times 20,400$, or 113,200 B. t. u. per gallon. The 0.0001 gallon extracted from 1 cubic foot of gas could contain $113,200 \times 0.0001$, or 11.3 B. t. u.

If the gas contained before treatment 1,000 B. t. u. per cubic foot, the residue of 0.9965 cubic foot would contain 1,000 minus 11.3, or 988.7 B. t. u. If 0.9965 cubic foot contained 988.7 B. t. u. the heating value per cubic foot is 988.7 divided by 0.9965, or 992.17 B. t. u. per cubic foot. Thus the extraction of 100 gallons per million of gasoline from a gas of 1,000 B. t. u. heating value results in a reduction to 992 B. t. u., or 0.8 of 1 per cent. The effect on a gas of any other heating value of gasoline yields can be similarly calculated.

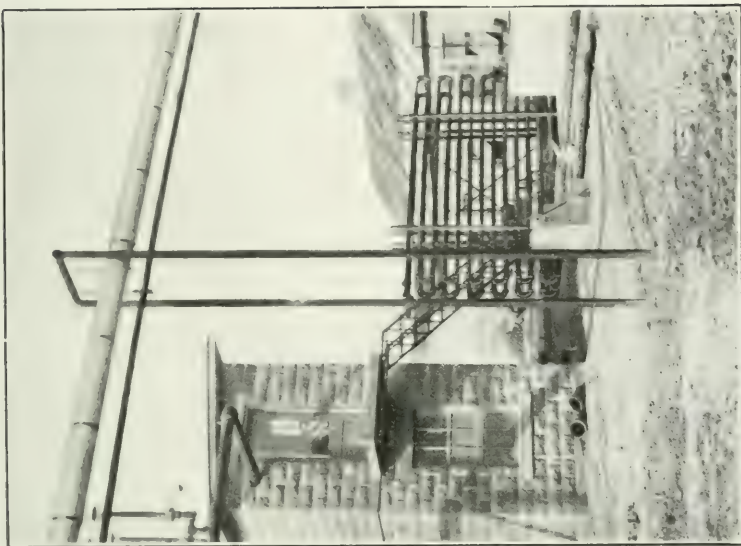
I submit herewith the result of some calorimeter tests of gases before and after removal of their gasoline content.

Inlet gas	1066 1070 1060	
Average		1065.3
Outlet gas	1058 1058 1058	
Average		1053
Loss due to gasoline extraction		7.3
Inlet gas	1068 1070 1070	
Average		1069.3
Outlet gas	1042 1046 1042	
Average		1043.3
Loss due to gasoline extraction		26
Inlet gas	1094 1092 1091	
Average		1092.3

^a Biddison, P. M., The reduction in heating value due to recovery of gasoline content very slight: *Natural Gas and Gasoline Journal*, August, 1917, p. 213.



A. EIGHTEEN-INCH BY 33-FOOT TOWERS; WORKING AT 30-POUND PRESSURE; SCAFFOLDING NOT YET REMOVED.



B. OIL-COOLING COILS DURING CONSTRUCTION. NOTE WIDE RETURN BENDS.

Outlet gas.....	{ 1067	
	{ 1062	
	{ 1060	
Average		1063
Loss due to gasoline extraction.....		29.3
Inlet gas	{ 1094	
	{ 1097	
	{ 1100	
Average		1097
Outlet gas	{ 1063	
	{ 1064	
	{ 1059	
Average		1062
Loss due to gasoline extraction.....		35
Inlet gas	{ 1086	
	{ 1087	
	{ 1084	
Average		1085.66
Outlet gas	{ 1071	
	{ 1066	
	{ 1071	
Average		1069.33
Loss due to gasoline extraction.....		16.33

The above tests are all from the same plant at different periods and the gasoline yield very closely the same at the time of each test. Calorimeter tests are not accurate to a degree closer than 4 B. t. u. This error, which may be a plus or minus error, makes the determination of the loss in heating value determinable only approximately by the calorimeter, since the error in measurement is so large a fraction of the quantity to be measured. However, the average of a large number of tests would show closely the loss due to extraction. The average of all the above tests shows a loss of 22.98 B. t. u. per cubic foot in heating value. For other data on this subject reference may be had to paper by G. A. Burrell, G. G. Oberfell, and P. M. Biddison before the Natural Gas Association of America, Pittsburgh, 1916; and Bureau of Mines Bulletin 88 (p. 60) and to articles appearing in the trade papers and journals.

OIL CIRCUIT AND TREATMENT.

The oil used as an absorption medium passes through the entire course of plant operation in a closed circuit of pumps, coils, interchangers, weathering tanks, and towers. Theoretically, no loss of this oil is necessary, but through leakage, breaks, and other irregularities in operations some oil is invariably lost, although in regular operation not enough to have much effect on costs.

ABSORPTION OILS.

The oils used as the absorbing medium in many plants are known as "mineral seal oil," "straw oil," and "gas oil," these being the

names given by refineries to products distilled after the distillation of all the water-white products, including heavy kerosene or stove distillate, as it is called in California practice. The light lubricating or spindle-oil stocks are at times used and have the same characteristics as those of the oils mentioned above, so far as regards their use in absorption plants.

The names of such stocks are a poor guide to use in selecting an oil for an absorption plant, since oil of the same name varies at different refineries, depending on the number of redistillations or treatments through which it has been put, and also the character of the crude treated. The properties to be considered in selecting oil are vapor tension, initial boiling point, and the viscosity at different temperatures.

Vapor tension is important because, as the vapor tension of the absorbing medium and the vapor tension of the liquid to be absorbed approach the same point, the capacity of the oil to absorb the liquid decreases and this limits the total percentage of vapor that will be absorbed and held by the oil. Temperature affects vapor tension, but will be considered later.

The initial boiling point of the oil used should be considerably higher than that of the heaviest of the gasoline fractions extracted from the gas, so as to leave a range of temperature between the final boiling point of the lowest of the absorbed fractions and the initial boiling point of the absorbing oil wide enough to insure a minimum distillation of the heavy yellow oil along with the gasoline vapor. This oil, when condensed, discolors the gasoline and makes it unfit for market without some treatment to remove these impurities.

The viscosity of absorption oil, while of less importance than other factors, may affect results in two ways—first, by making pumping and equal distribution to all towers or units more difficult, especially in cold weather; and, second, by the oil not spreading in thin films and running freely over the baffles in the tower.

In regard to emulsification of absorption oil, R. O. Neal,^a chemist of the Bureau of Mines, says:

Information regarding the emulsification characteristics of the absorption oil is helpful, although not necessary in choosing an absorption medium. Some oils have a tendency to form emulsions with water when they are agitated in passing through pumps into the flow tanks, stills, and absorbers (more especially horizontal absorbers). In one plant where the difficulty had resulted in low plant extraction, it was discovered that the trouble was due to the large per cent of emulsion (35 per cent), that was contained in the oil and would not separate out in the still.

^a Neal, R. O., Personal communication.

The Baumé gravity of the oil, although an indication of the characteristics, is too indefinite for a standard by which to be guided. The oils found in use range from California crude having a gravity of 19° B. to light-yellow mineral seal oil having a gravity of 38° B. A plant in California found that a refined oil with a gravity of 36° B. had too low an initial boiling point and too high a vapor tension for use even in a steam still, and is now using successfully a narrow cut of oil (27° B.) from Fullerton crude. A narrow cut of oil, that is, one with initial and final boiling points not too widely separated, is recommended with an initial boiling point not lower than 450° F. The Baumé gravity of the refined absorption oils in use ranges from 37° to 27° B, the tendency being toward the lower gravities and toward narrow cuts. After having passed through the plant a few times the mineral seal oil gains about one degree Baumé gravity, through a small fraction of gasoline that is not extracted by a single steam distillation. At plants where gas oil is used a decrease in Baumé gravity often occurs after the first passage of the oil through the still, because gas oil is not entirely freed from the kerosene fractions in refining. This small fraction of kerosene will give the gasoline made a high end point, especially the gasoline made just after the addition of fresh oil to the circuit. An operator of a low-pressure plant in the Mid-Continent field uses oil complying with the following specifications:

	° F.
Initial boiling point.....	418
90 per cent over at.....	679
96 per cent over at.....	720
Viscosity factor, 45 at 100° F. Saybolt.	

Such specifications are unusual because, first, the percentage of oil distilled at temperatures above that at which this oil will begin to crack is large, and, second, the initial boiling point is lower than that most engineers desire. The following specifications define an oil which is better suited to this work and which is much used for this purpose:

Specifications for an absorption oil.

Flash point.....	247° F.
Fire test.....	262° F.
Gravity.....	37° B.
Over point.....	450° F.
End point.....	695° F.
Viscosity, 1.6 E. D. (at 20° C.)	

DISTILLATION.	
Per cent.	Temperature, ° F.
10.....	528
20.....	540
30.....	556
40.....	565
50.....	572
60.....	572
70.....	595
80.....	608
90.....	633
100.....	695

OIL PUMPS.

Two sets of pumps are usually installed, one to pump oil against the pressure in the towers, and the other, called transfer pumps, for handling the oil at low pressure to and from the stills, interchangers, coils, and storage.

In many plants duplex steam pumps have been used, the exhaust steam going to the steam still, though this practice is sometimes condemned as wasteful of gas used for fuel under boilers. In later plants are gas engines directly driving either plunger or duplex geared pumps, or driving generators that supply electricity to run the pumps and compressors. In these plants the boilers generate steam merely for still use. The fuel economy is obvious, for gas engines use about 12 cubic feet of gas per horsepower-hour, whereas boilers use 60 to 120 cubic feet.

In plants where the oil circulated in the towers must be pumped against pressures of 100 pounds or more, the oil from the heat exchangers is cooled, in water-cooled coils, after passing through the high-pressure pumps, because pumping the cold oil at high pressures raises its temperature 6° to 7° F. The plant that noted this rise in temperature used steam duplex pumps, so part of the heat entering the oil was probably transmitted by conduction from the steam end.

COIL AREAS USED IN COOLING ABSORPTION OIL.

Oil from the pumps under the full tower pressure passes into a header at the low end of continuous return-bend coils, through which it passes upward to a header connecting with the top pipes of the different water-cooled coils. The number of coils and number of pipes in each coil depend on the total area necessary to accomplish the cooling and on the size of pipe used. Pipes of 2, 3, and 4 inch diameters are used. The smallest pipes, 2-inch pipes, expose the greatest radiating area in proportion to their oil capacity and are generally used in coils cooled by water and air in towers and similar cooling apparatus.

Figure 15 shows a coil of this character having 13 pipes 4 inches in diameter. The coils exposed an area of 7.64 square feet of radiating surface per gallon per minute when the plant was working at 60 per cent capacity. When the plant ran at full capacity the coils exposed an area of approximately 4 square feet per gallon per minute.

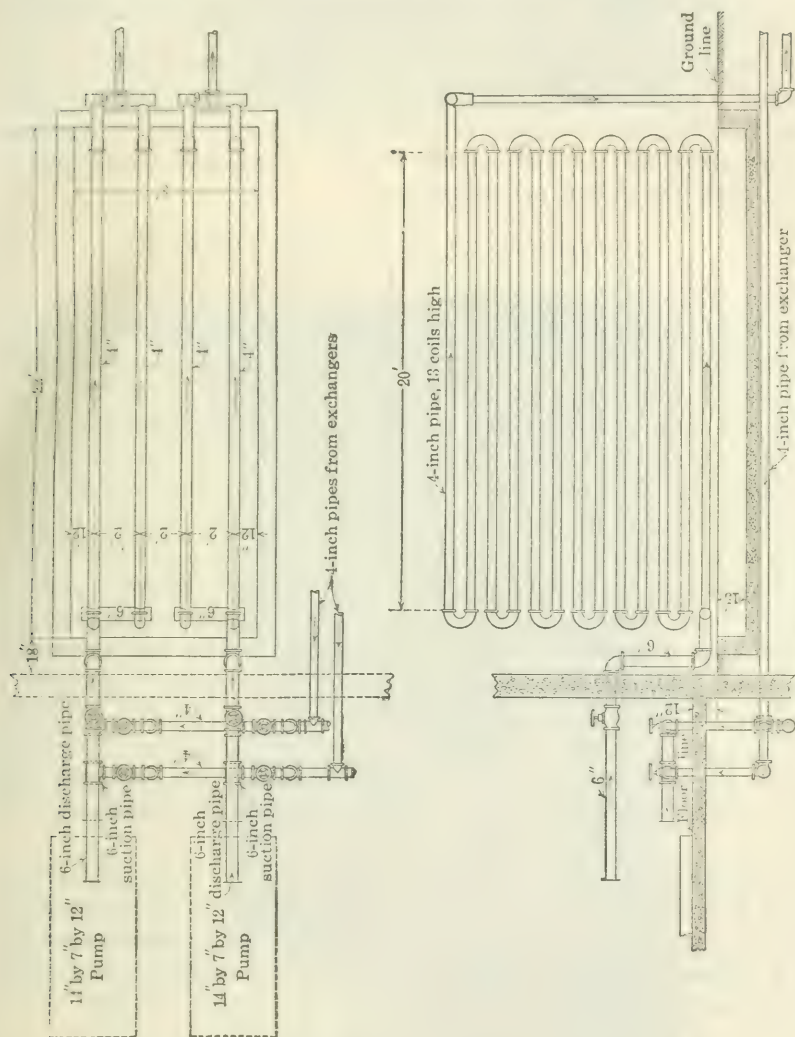


FIGURE 15. Cooling coil for absorption oil.

At the time of inspection the temperature reduction between inlet and outlet was 70° F. (from 150° to 80° F.). The water used came directly from wells on the property, and was circulated without being cooled in towers. In dry hot climates the tower cooling of the water is necessary.

In most oil fields coils of 2-inch pipe 20 or 40 feet long with return bends placed in cooling towers are preferred. The practice is similar to that for cooling gas from compression plants, as described in Bureau of Mines publications.^a

Between 3 and 4 square feet of radiating area per gallon per minute is sufficient if 2-inch pipe is used and the oil is previously cooled in an efficient heat interchanger on its way from the still to the water-cooled coil. An operator in an eastern field uses 6 feet of 2-inch pipe, or about 3 square feet per gallon of oil circulated per minute.^b Another factor used is 2 square feet of radiating area per 1,000 gallons of oil a day; that is, 2.88 square feet, or about 5.50 linear feet of 2-inch pipe per gallon per minute.

CONSTRUCTION OF COOLING COILS.

Plate VII, *B*, shows oil-cooling coils during construction, and Plate VIII, *A*, shows the coils completed, with a louver tower used as a protection and to direct air over the coils, and not as a water-cooling tower. The louver extends only as high as the top of the pipes.

The spacing of pipes and coils that depend on the action of air and water for their cooling effect on oil or vapor has caused trouble, yet is seldom brought to the attention of the plant operators. Although conditions may force closer spacing, it is well when possible to place pipes in a continuous coil so that an air space not less than twice the diameter of the pipe will be left open vertically between pipes of the same coil, and a space 8 to 10 times the diameter of the pipe will be left open horizontally between sets of coils. This rule is entirely empirical, but is based on installations that have proved satisfactory. Another rule is to flow hot oil upward whenever possible, especially during heating, to avoid the formation of gas pockets. These rise against the flow of oil if the oil is flowing downward, lodge at high points, cause "bumping," and reduce the flow by constricting the area.

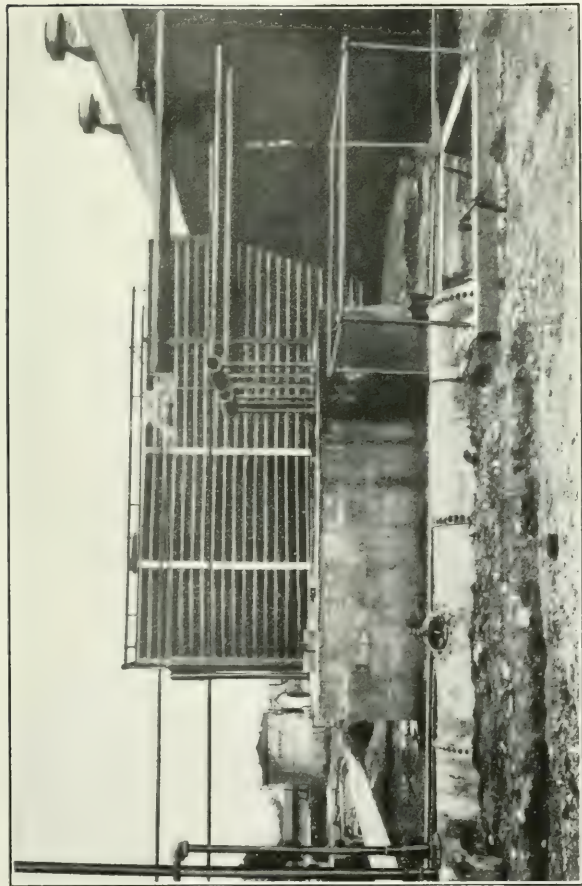
From the water-cooled coils the oil goes to the pipe header from which it is distributed to the absorption towers. The temperatures of the oil in the pipe header is between that of the atmosphere and 40° F. below atmospheric, and the pressure is 5 to 100 pounds above that of the gas to be treated.

FLOW OF OIL THROUGH ABSORPTION TOWERS.

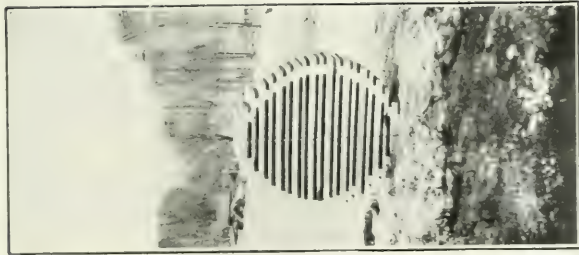
Where two or more absorption units are connected in parallel, the oil from the high-pressure pumps and the cooling coils is divided as

^a Dykema, W. P., The recovery of gasoline from natural gas by compression and refrigeration: Bull. 151, Bureau of Mines, 1918, 123 pp.

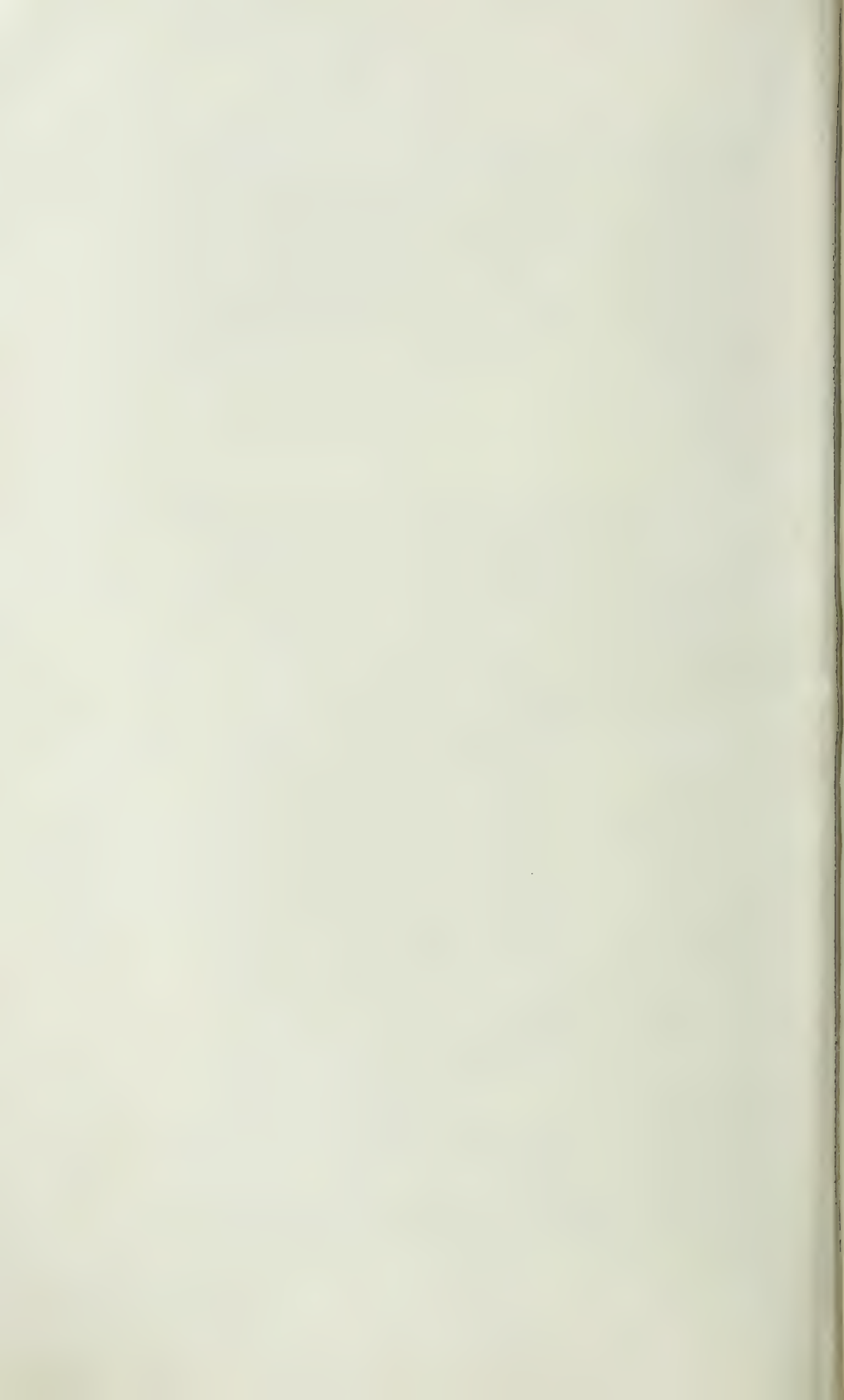
^b Radiating areas throughout this bulletin are computed on the nominal diameters of the various sizes of pipe used.



A. COILS SHOWN IN PLATE VII, B. COMPLETE WITH LOUVER TOWER.



B. SINGLE SECTION OF WOOD
BAFFLE OR FILLER.



it flows from a header into smaller lines that carry it into the distributing device inside of towers above the baffles. In order to divide the oil equally among the different units of baffles, an orifice may be inserted in the line at some point between the oil header and the tower connection. In figure 13 (p. 25) this orifice is shown, as are the methods of connecting the oil line with the tower and distributor.

Figure 16 shows the detail of this distributor. The pressure used is 5 to 10 pounds above that of the gas.

Other devices for dividing the oil equally over the baffles area are perforated pipes either circular or with 4, 6, or 8 radiating arms, sprays, slotted pipes, and troughs. There seems little choice among these types, and no trouble with any of them was reported to the writer.

METHODS OF EXPOSING OIL TO GAS.

Obviously, the best practice is to expose the largest possible surface of oil to the gas with least constriction of the cross-sectional area of the pipe or tower. As it is only those oil surfaces exposed to the gas that can absorb vapor, a large surface of oil should be exposed so that each molecule of condensable vapor in the gas may at some period of transmission through the tower be in actual contact with the oil and be absorbed by it.

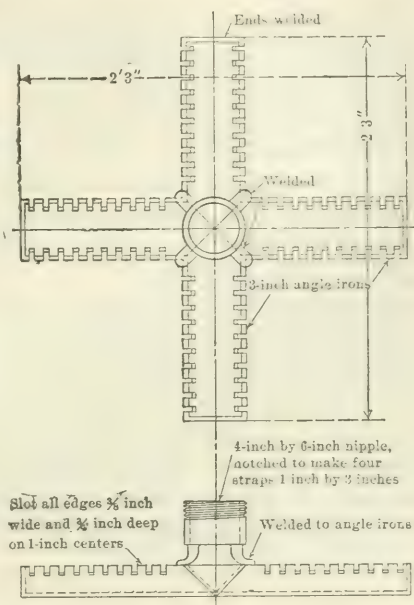


FIGURE 16.—Oil distributor.

OIL SPRAYS.

Oil sprays are being used at tanks or towers through which gas is passing, either as a preliminary treatment before the gas passes to the towers or final extractors, or as the final treatment at the top of towers. In figure 14 (p. 27) the oil is sprayed into the tower at a pressure of 100 pounds above that of the gas. Around the tower wall six spray nozzles are set 60° apart, and inclined downward 30° from the horizontal, so that a fine mist of oil opposes the rising current of gas and the oil surface exposed is the maximum. The fresh

oil comes in contact with gas that has passed through the wood baffles shown below, and has been relieved of part of its content of condensable vapor. Oil from spray nozzles settles on the baffles and continues downward, still in contact with the gas and being enriched by the gasoline vapors, until it reaches the bottom of the tower.

Some operators object to sprays, contending that with many oils the water in the oil coming from the still will form an emulsion when forced through a small orifice or a spray nozzle.

BUBBLING.

Gas is at times bubbled through oil either in the bottom of towers after the oil has passed over the baffles, or in tanks. The testing apparatus shown in figure 11 (p. 21) shows the principle of bubbling gas through oil. In large tanks the contact obtained is not satisfactory because of the formation of large bubbles that, rising through the oil, allow only a relatively small proportion of the surface of the contained gas to come in contact with the oil, and when the gas velocity is high such bubbles tend to carry the oil through the tower and into the gas lines.

At one plant the towers are filled two-thirds of the way to the top with brickbats, and the oil level is held half way up. The gas bubbles upward through the oil and bricks to the top of the oil and then passes through brick baffles counter-current to the descending oil, receiving a second scrubbing action, and finally ascends through an unbaffled spray to the gas discharge. Counterflowing over baffles has proved more efficient in practice, whereas bubbling through oil has limited application, and only a few engineers are willing to install this type of apparatus.

BAFFLES.

Many materials have been used for spreading oil into thin surfaces in the presence of gas. Among them are stone, tile, and wood and steel shavings.

In the experiments by Biddison and Burrell, on which the design of the plant of the Ohio Fuel Supply Co. at Homer, Ohio, was based, round cobblestones were used in the vertical absorbers to spread the oil in thin sheets while in contact with the gas, and worked admirably, but constricted unduly the area of the tower as compared with the actual surface exposed. When the plant was built, 4 by 5 by 6 inch hollow wall tile was put in the place of stones; these tiles have given satisfaction as baffles, but have crushed or decomposed somewhat and particles of the burnt clay follow the absorption oil to low points in its circuit, from which they have to be

drained. Vitrified tile or pipe would be stronger and would not disintegrate. Fragments of vitrified sewer pipe have been used satisfactorily to expose large surfaces of liquids to vapors in towers.

One plant uses successfully two sizes of carefully screened crushed rock, packed in towers of 36-inch diameter. However, the great weight of such filling must be considered, as well as the cost and time of cleaning if the towers should be clogged with dust, dirt, or other impurities, and the constriction of the cross-section area, which increases the flow velocity. A cobble-filled tower showed by test that only 32 per cent voids were left for the passage of gas. Another plant having towers 20 inches in diameter is using cobbles 3 or 4 inches in diameter, in the manner described by Burrell^a and used in his experimental work.

When stone, tile, or other heavy baffling is used, the weight is supported on a frame set on the tower bottom as shown in figure 13 (p. 25).

Wood baffling has been proved satisfactory in the treatment of coke-oven gas and is being widely adopted in the treatment of natural gas, because of its lightness and the ease of making different shapes and thicknesses. It can be worked into baffles that expose a large surface yet constrict the area but moderately. In one plant the writer saw lath used for baffling in such a way as to give 75 per cent voids. Metal strips would seem to offer even greater advantages than wood, but their use has not been observed.

Steel shavings or cuttings are being tried by several companies. The quantities used are 15 pounds to 30 pounds per cubic foot, giving a high porosity and a large area on which to expose the oil.

WOOD BAFFLES.

Wood baffles are made of different widths and thicknesses of wood strips, built up as gratings. The spaces between the strips are usually two or three times the thickness of the strips. Widths and thicknesses range from house lath to 1-inch by 6-inch boards. The gratings are set in the towers so that each supports the one above it, each set of strips being placed at an angle with those below. In some towers the angle is 90°; in others, it is less and gives a spiral effect. The relative efficiency of the various angles of setting has not been determined.

Figure 14 (p. 27) shows a unique method of inserting baffles. An iron bolt and perforated plates at the top and bottom hold the baffle cartridge together, allowing the cartridge to be handled as one piece. The baffles, as shown, are strips of wood, $\frac{1}{2}$ inch by 6 inches, spaced

^a Burrell, G. A., Biddison, P. M., and Oberfell, G. G., Extraction of gasoline from natural gas by absorption methods: Bull. 120, Bureau of Mines, 1917, 71 pp.

$\frac{1}{2}$ inch apart. A section of wood baffle, or filler, having wedge-shaped slats placed so that the thin edges alternate is shown in Plate VIII. *B* (p. 36).

In many towers of large diameter, wood gratings, or sets of baffles, are placed one on top of the other all through that part of the pipe used in baffling; in others, 4 or 5 feet of baffle gratings is supported on lugs, or angle-iron ribs, and an open space of about one foot is left between sets of baffles to allow the gas currents to mix before passing through the next baffle above. The angle-iron ribs act as oil baffles, distributing the oil deposited on the tower wall over the wood gratings below.

Wood parts always should be made of dressed lumber, as the use of rough pieces has caused trouble from splinters and fibers and consequent cleaning of valves, tanks, stills, and other places offering lodgment.

In the opinion of the writer neither the most useful material for baffles nor the most efficient percentage of voids has been definitely determined. Some operators have made tests that indicate the most efficient voidage for a given material; none, so far as the writer knows, has tested more than one or two materials in an endeavor to determine the factors for plant construction. One company has adopted as its standard form of tower filling a perforated round tile that gives a voidage of 50 per cent. This tile has proved satisfactory for use with the pressures, flow velocity, and gasoline content of the gas treated.

The problem seems to be one of combining the factors of open space and exposed surface in such a way as to obtain the maximum of each without undue friction or reduction of pressure.

SEPARATING OIL AND GAS IN TOWERS.

At both the top and the bottom of a tower open unbaffled lengths are left to permit the separation of gas and oil. At the bottom the gas inlet is placed between 3 and 5 feet above the tower base, and the oil outlet as near the bottom as possible. More or less oil from the baffles collects in the lower chamber before being discharged from the tower, so that the gas has a brief time to separate from the oil before going to the weathering tank.

The gas outlet is placed close to the top of the tower, and the oil inlet 5 to 7 feet below the top, so that there is left 5 to 7 feet of open tower. A much shorter space might be left here, as well as at the bottom, and the final separation of the oil from the gas might be completed in a trap in the vertical gas-discharge line, thus allowing a greater length of tower to be used for baffles. A trap of the type used to separate the oil and gas outside of the tower is shown in Plate

VI, A (p. 29). The trap discharges the oil collected from the gas into the oil-outlet line at the bottom of the tower. This practice is consistent with the tendency to increase the height of tower to gain greater length in which baffles may be placed, for it has the same effect, by permitting, as it does, a greater part of the tower to be used for bringing the oil and gas into intimate contact. At present only one-half to two-thirds of the tower is filled with baffles. The remaining space at top and bottom is used to separate the oil and gas. Usually the space at the top of the tower is left as an open separating chamber. Figure 17 shows an oil trap for placing inside the tower, as used by an eastern company. This trap is placed above the oil inlet and below the gas outlet, being suspended from the top of the tower by a bail bolted to an angle iron. The action of the trap is self-explanatory.

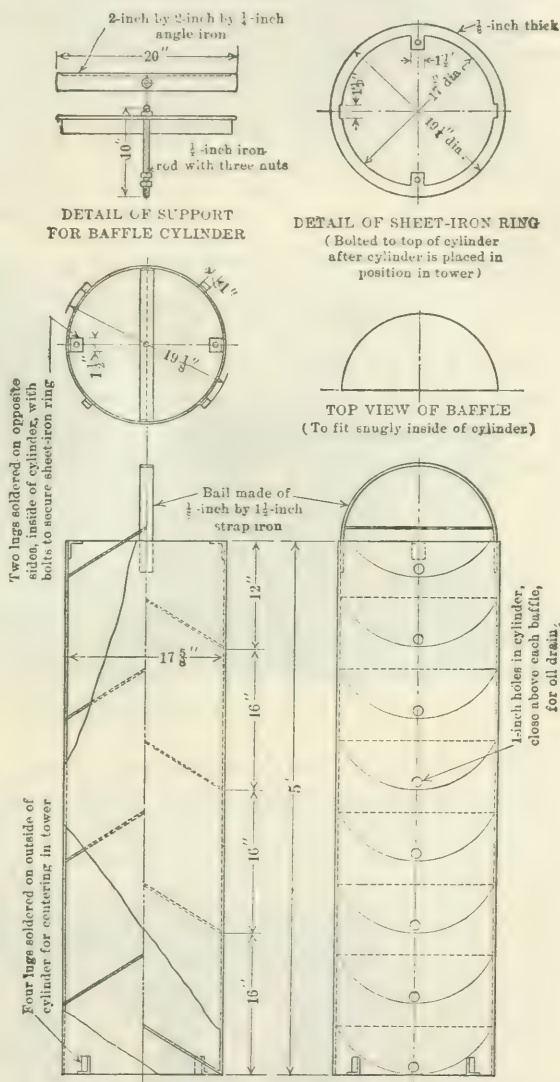


FIGURE 17.—Oil trap, placed inside of tower. Cylinder and baffles made of 16-gage galvanized sheet iron; baffles soldered to cylinder.

OIL TRAPS OUTSIDE OF TOWERS.

The traps most used embody the principle of enlarged diameter, either of pipe or a tank, so that the velocity of the passing stream of gas is reduced, and any entrained particles of oil have opportunity

to separate from the gas and collect. Many traps are so designed as to insure a change in direction of flow, the oil settling to the lower part of the trap. The oil flows from the bottom of the trap, controlled by back pressure, or is automatically discharged.

Water traps used in steam lines work satisfactorily, if large enough, but are more expensive and are no more efficient than traps

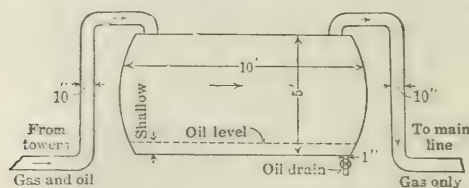


FIGURE 18.—Oil trap placed in discharge line.
Not drawn to scale.

built on the ground of various standard sizes of pipes. Plate IX, A, shows a trap built of standard pipe and fittings through which 40,000,000 cubic feet of gas passes daily at 250 pounds pressure. There are many designs of efficient and inexpensive traps. Plate X, A and B, and figure 18 show traps with prostrate tank.

Regardless of the separating devices in the towers, the gas always passes through some form of trap before it goes to the gas mains.

QUANTITIES OF OIL.

The quantity of oil used is computed in the same terms as the condensable content of the gas, that is, in gallons per 1,000 cubic feet, so that all primary operations can be referred to the same base, the volume of gas treated.

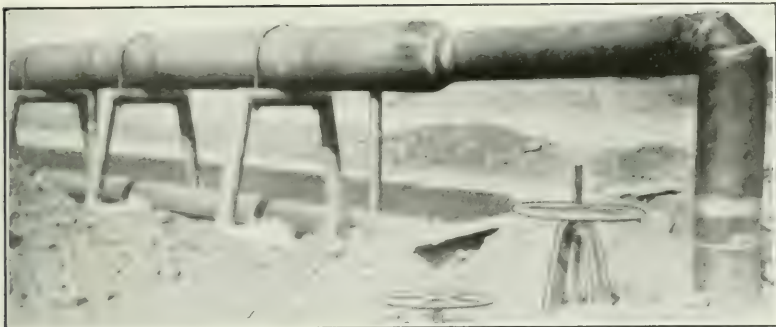
SATURATION.

The table following shows the relation of pressures, saturation, oil circulated, and gasoline content, as found at the plants listed:

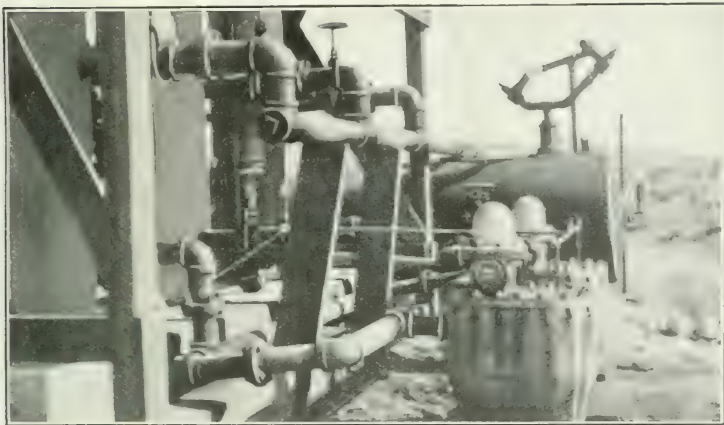
TABLE 4.—Saturation of oil and recovery of gasoline at plants visited.

Plant No.	Pressures.	Oil circulated.	Satura- tion.	Gasoline recovered.
	Pounds per sq. in.	Gallons per 1,000 cu. ft.	Per cent.	Gallons per 1,000 cu. ft.
1.....	175	5.95	2.55	0.152
2.....	172	3.80	5.35	.202
3.....	135	4.96	6.30	.264
4.....	142	2.61	6.60	.173
5.....	30	20.00	2.50	.500
6.....	25	18.00	2.10	.375
7.....	250	5.00	4.00	.200
8.....	250	5.00	6.50	.325
9.....	5	70.00	5.00	3.500

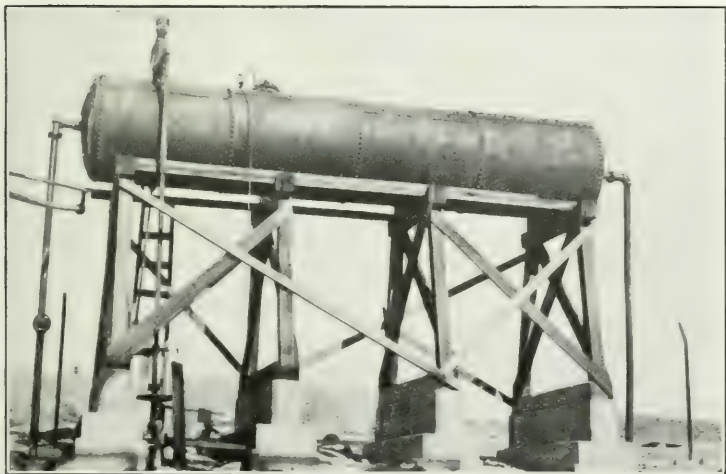
This table shows far too few plants to serve as a basis of final conclusions or for the development of an empirical formula for calculating the quantity of oil necessary for the complete extraction of gaso-



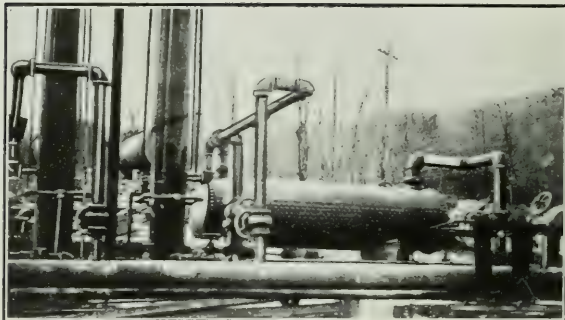
A. PIPE OIL TRAP, USED ON GAS LINES FROM TOWERS TO COMPLETE THE OIL AND GAS SEPARATION.



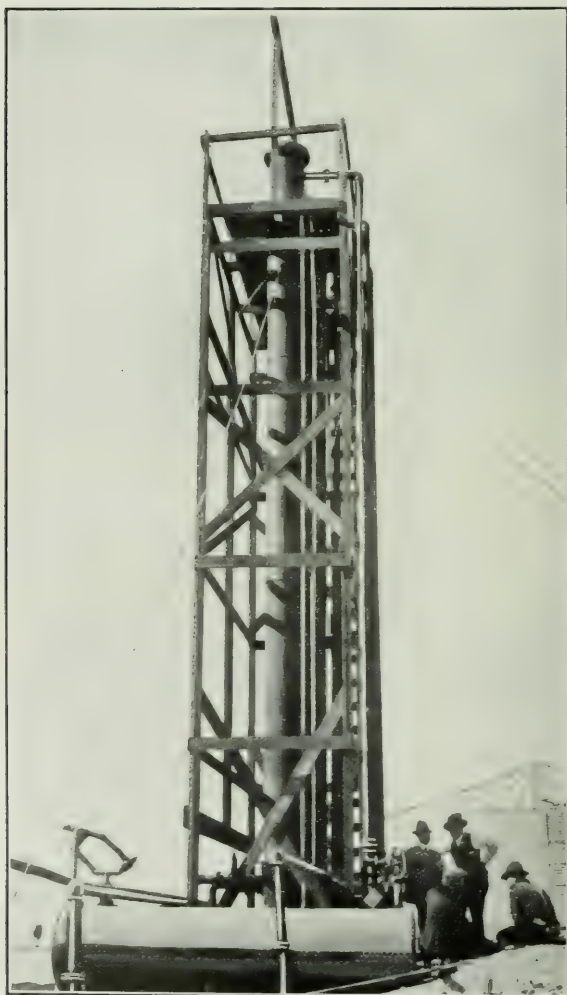
B. TWO AUTOMATIC TRAPS.



C. WEATHERING TANK MOUNTED ON HIGH FRAME, TO INSURE GRAVITY FLOW TO STILL AGAINST PRESSURE OF 2 TO 5 POUNDS IN STILL.



A. HIGH-PRESSURE, PROSTRATE TANK USED AS OIL TRAP.



B. LOW-PRESSURE, PROSTRATE TANK USED AS OIL TRAP.

line from gas of varying gasoline content at any given pressure. However, the table shows that the limit of saturation may be more than 4 per cent, which was once considered the maximum for high-pressure treatment. Although oil begins to absorb gasoline imperfectly when the saturation is 4 per cent, the oil can still absorb large amounts of gasoline vapors from fresh untreated gas.

This point is demonstrated in multiple-coil absorbers using separate volumes of oil in each coil or unit. In experiments and tests with such absorbers as shown in figure 10 (p. 20) and Plate I, *B* (p. 16) the oil in the first chamber has been saturated to 10 per cent, the oil in the second chamber became saturated to 4 per cent, and that in the third chamber about 1 per cent of its volume. In the fourth and fifth chambers the volume increased and the Baumé gravity became higher, but the amount of gasoline was so small as to be difficult or impossible to distill out and measure with the usual laboratory equipment. The increase in volume and the increase in Baumé gravity are due to the absorption of gas, the absorption of vapors too light to be condensed as they issue from the still, or to both. Although the plants installed do not treat the gas in several separate units each with its circulation of fresh oil, the countercurrent flow of oil and gas in a tower is quite similar, the richest gas meeting first the oil that has been exposed to the gas in the upper part of the tower. This brings up again the point previously mentioned, that of height of towers, but in regard to saturation rather than to construction.

HEIGHT OF TOWER AS A FACTOR IN OIL CIRCULATION.

Operators now are planning to increase the height of towers with the object of reducing the amount of oil circulated and increasing the time of contact between oil and gas, thus obtaining equal recovery with less power for pumping and less heat in the stills. Decreasing the amount of oil circulated means that the saturation must be increased, and this will be accomplished by longer exposures of oil to gas in the counterflow system of treatment.

The amount of oil circulated, besides varying with the pressure, height of tower, and condensable content recovered from the gas, varies with the temperatures of oil and gas, and with the characteristics of the hydrocarbons recovered. At the plants the writer visited the greatest quantity of oil circulated was 70 gallons and the least was 2.61 gallons per 1,000 feet.

PUMP CAPACITY.

When an absorption plant is being designed from data obtained in tests, it is well to have the capacity of pump and still somewhat

larger than the maximum indicated by the tests, to cover the possibility of the chosen height of tower not being efficient enough to give the total extraction desired. This deficiency in the towers may develop because of insufficient height, the type of baffling used, the high temperature of the oil, and gas or some other factor, and the quickest and cheapest method of overcoming this fault, at least temporarily, will be by increasing the flow of oil. The most flexible and easily adjusted part of plant operation is the oil circulation, and therefore it is the part where control should be provided. Hence the size and reliability of the pumps should be carefully considered before a choice is made.

EFFECT OF TEMPERATURE.

The temperature of the oil and gas during the period of absorption decidedly affects the quantity and quality of the vapors absorbed and consequently the efficiency of the process. Lowering the temperatures lowers the vapor tensions of the condensable fractions of the gas and thereby renders them more easily absorbed. Moreover, the absorbent, as is true of all liquids that absorb gases selectively, has a greater capacity for taking in and holding vapors and gases. Hence it is clear that lowering the temperatures of the oil and gas permits a reduction in the quantity of oil circulated or an increase in the percentage of saturation.

However, it is evident that greatly reducing the temperature and maintaining the same flow of oil would increase the production only a little, as the lightest fractions absorbed at extremely low temperatures, if they could be condensed after distillation, would be too volatile to ship. In distilling and cooling the light uncondensable vapors would have a tendency to carry valuable fractions through the coils. Just how much the flow of oil could be reduced with lowering of temperature has not been determined, but there are decided advantages in keeping the temperatures in the towers well below the overpoint of the gasoline produced, which is usually about 80° F. In order to keep the gas at the same temperature as the oil, many operators cool the gas just before it enters the absorbers by passing it through a coil under water sprays in a louver tower. This should always be done when the gas lines lie on or near the surface of the ground for any distance before they enter the absorption units.

In Oklahoma, Texas, and California a well-designed louver tower with enough coil area should cool the gas 20° to 40° F. below outdoor temperature during the hot dry season.

The temperature of the oil and gas should be nearly equal and as low as the cooling system used will permit. In an Eastern plant the gas entering the tower at 60° F. was treated with oil at 84° F. and

temperature of the gas was raised 10° to 70° F., in passing through the tower. Such increase of temperature is undesirable. The temperature of the oil and gas can not be lowered so far by atmospheric and water cooling as to cause the absorption of undue quantities of uncondensable fractions. Such low temperatures can be developed only by some process of refrigeration. To recapitulate, the quantity of oil circulated through the absorption tower may be reduced without lowering the extraction if the oil and gas temperatures are lowered or a greater percentage of saturation is used.

The following table gives an idea of the temperature changes of both oil and gas in passing through the absorption towers:

TABLE 5.—Oil and gas temperatures at inlet and outlet of absorption towers. Average for 24 hours.

	Plant No. —				
	1	2	3	4	5
	° F.	° F.	° F.	° F.	° F.
Temperature of gas entering tower.....	70	68	39	117	116
Temperature of gas leaving tower.....	73	72	50		
Temperature of oil entering tower.....	95	97	81	101	96
Temperature of oil leaving tower.....	66	64	42	106	101
Temperature of atmosphere.....	70	72	30		

Figures for plants 1, 2, and 3 were taken in winter, and those for plants 4 and 5 were taken in summer. The temperature of the oil leaving the towers in plants 4 and 5 show that cooling systems used were entirely inadequate and could easily have been improved. As the height of the towers and the gas pressure are fixed, the temperature of oil and gas will be one of the factors determining the quantity of oil that must be circulated, this becoming less as the temperature is lowered. This factor of temperature seldom becomes evident, as the quantity of oil to be circulated is generally determined at commercial plants under the usual working conditions; or at experimental plants under practically uniform conditions.

FLOW OF OIL FROM TOWERS.

Two distinct methods of discharging oil from towers have been developed. In one the oil flows through a self-dumping trap that automatically reduces the pressure. In the other the oil flows from the towers into a collecting header from which it goes to a receiving tank under the full tower pressures.

AUTOMATIC TRAPS.

In the first method the automatic self-dumping traps shown in Plate IX, *B* (p. 42) immediately reduce the pressure to that in the

weathering tank, which ranges from 2 to 40 pounds per square inch. Plate IX, *C* shows a weathering tank on a high frame; the object of placing the tank on high ground and a frame is to obtain enough pressure to force the oil through the interchangers and into the still without the use of pumps.

The number of traps required depends on the quantity of oil passing through the towers, and on the capacity of the traps used. Many plants include a trap for each tower and some, as shown in Plate IX, *B*, take the oil from all the towers and discharge it through a manifold header to traps of the required capacity. Oil-level regulators are also being used to obtain automatic discharge from towers.

FLOW TANKS.

In the second method, using a collecting header, the oil flows directly from the tower under the full gas pressure and is discharged to the weathering tank through an automatic level-regulator and valve of the type used on stills and other apparatus. This method requires but one automatic device for the discharge of oil from any number of towers, and has the advantage of requiring less attention, lower upkeep charges, and smaller first cost. The tank or receiver held under tower pressure may be made of standard pipe and fittings. One such unit installed in an eastern plant was built of a 20-foot length of 30-inch pipe set horizontally.

OIL WEATHERING TANKS.

Weathering the absorption oil in tanks at a reduced pressure before heating and distilling has become the general practice. The object of weathering is to relieve the oil of gas taken up during the scrubbing process, as this gas can not increase the gasoline yield and is troublesome and detrimental in the distilling and cooling. Regardless of the higher hydrocarbon selectively absorbed from the gas treated, in making a complete extraction of those higher fractions that after distilling can be marketed as gasoline, different proportions of all of the other hydrocarbon constituents of the gas, will also be in the oil, even after the oil has been weathered at pressures lower than those in the towers. As soon as the pressure on the oil is reduced, these lighter fractions begin to distill from the gas. Some operators believe these fractions carry with them valuable quantities of the condensable fractions. The quantities will vary in different plants, and whether they are always large enough to be worth extra units for their recovery has not been determined, but the belief is

becoming general that these gases are too lean for profitable treatment by compression.

Some operators treat the gases discharged from the weathering tank either in the compressor or in an absorption tower that treats also any still vapors not condensed in the water-cooled coils. Other engineers doubt the usefulness of treating these gases, claiming that the recovery is too small to justify the added cost of equipment and operation. At some plants, the treated gas is passed back to the outgoing gas mains, as its heating value is higher than the other treated dry gas. In this way the absorption plant is relieved of part of the charges for smaller volume and lowered heating value of gas, consequent on the removal of the gasoline. In some plants this gas, with the uncondensed still vapors, is used in gas engines or under the boilers instead of gas from the outgoing mains, thus saving fuel and reducing costs. To allow any vapors of gas to flow into the atmosphere is dangerous and needlessly wasteful. If the gases that leave the oil in the weathering tank were held in the oil while it is being heated in interchangers and stills, gas pockets might form in the interchanger pipes and there might be an excessive liberation of gas in the still; this gas when coiled later in the vapor coils would hinder the precipitation of the condensable fractions.

As stated, the pressure held on the weathering tanks ranges from 2 to 40 pounds, according to the pressures used in the tower and the method of flowing the oil through the heat interchangers. The weathering tank is usually a horizontal cylinder constructed of boiler plates. A valve set to open at the desired pressure controls the gas outlet which discharges into a gas line to the compressor or the absorption unit, or to the boilers.

If the oil level in the weathering tank is not held automatically at a given level, the tank may be, and often is, used as a receiver or temporary reservoir for oil when the quantities of gas being treated or of oil circulated vary. This tank is the only unit in the system where such storage or variation of content is allowable or possible, for the oil must move continually through the other units and usually to their full capacity under the working conditions. If the weathering tank can not be used in this way there must be an extra tank to care for irregularities in the quantity of oil circulated.

From the weathering tanks the oil is forced through the heat interchangers to the still, either by transfer pumps working at a pressure of 15 to 25 pounds to overcome friction in the interchangers and the head due to the height of the still inlet, or by the pressure in the weathering tank. The rate of flow is regulated by the speed of the pump, or if the oil flows under tank pressure, by the discharge-valve regulator or a hand valve in the line to the still inlet.

HEAT INTERCHANGERS.

The primary function of heat interchangers is to save heat and fuel. In the absorption process the interchangers also cool the residual oil flowing from the still. Otherwise this cooling would have to be done entirely in water and air cooled, or double-pipe water-cooled coils. At a refinery where the residual oil is to be pumped through a long pipe line, cooling below a certain temperature is neither necessary nor desirable; but in absorption practice lowering the temperature of the oil from the still lessens the cooling to be done in the water tower, and raising the temperature of the saturated oil saves much boiler horsepower.

No radically new designs of heat interchangers have been developed in absorption practice, the types being of the same general plans as those used in refineries.

In absorption plants the conditions for developing efficiency in the heat interchangers are ideal. The amount of oil going to the still is only 6 or 7 per cent more than that from the still, the viscosity of the two oils is little changed, and the oil contains no fraction, such as wax, that will be precipitated or solidified by any decrease of temperature. In refinery practice an interchange of 22 B. t. u. per square foot per degree of mean temperature difference per hour is considered exceptionally good practice and is far above the average efficiency obtained in topping plants.

One absorption plant claimed an interchange much higher than mentioned above, but complete data could not be obtained by the writer.

Lucke,^a gives 50 to 75 B. t. u. per hour per square foot per degree of mean temperature difference as the average practice for the transfer of heat between brine and ammonia in ammonia absorber cooling coils. The difference, in heat transfer, between refinery or absorption practice and ammonia absorbers is due to the specific heats of the liquids concerned being different, and to the fact that in ammonia absorbers latent heat has to be considered. Also, the difference is partly due to the oil circulated in refineries being more viscous, and therefore being not only more difficult to pump at the high velocities necessary for maximum heat transfer, but requiring pipes of large diameter in which the rate of transfer is not so rapid as in smaller pipes.

The rate of heat transmission depends on the velocity of the fluids along the separating walls of the pipes as well as on the difference in temperature of the two liquids. Lucke^b says of the velocity function:

^a Lucke, C. E., Engineering thermodynamics, 1914, p. 550.

^b Lucke, C. E., Work cited, p. 539.

"The quantity of heat transmitted is found to be proportional to the velocity of the fluid, to some power. when one fluid is in motion, and to some power of each, not necessarily the same, when both move."

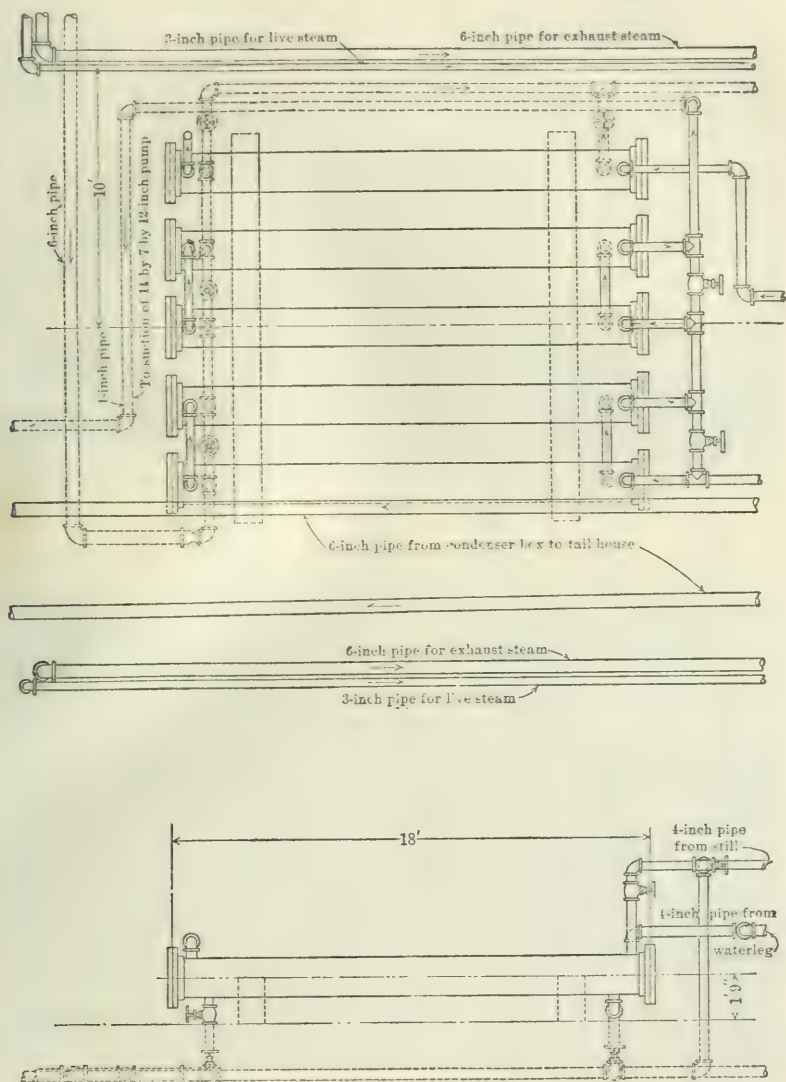
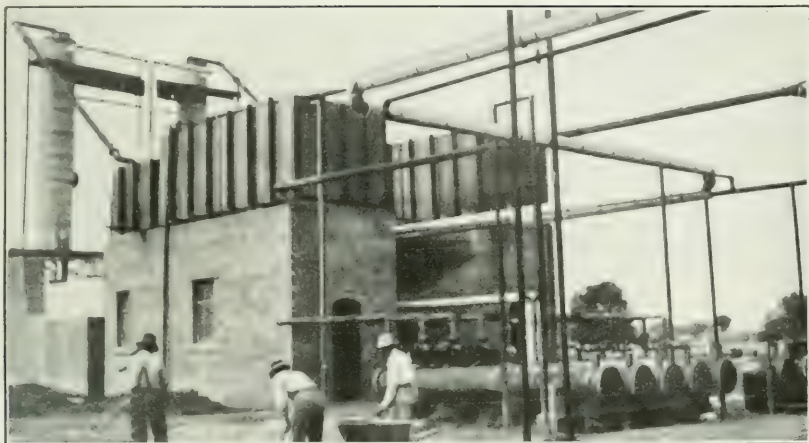


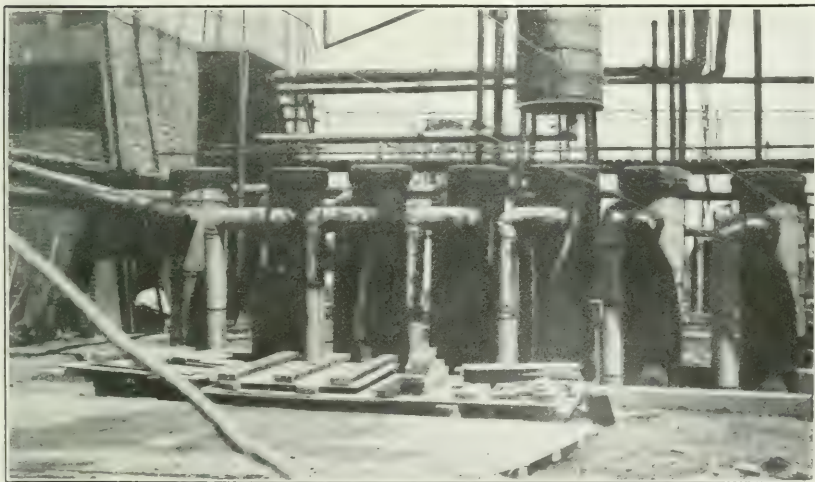
FIGURE 19.—Tubular heat interchanger.

TYPES OF INTERCHANGERS.

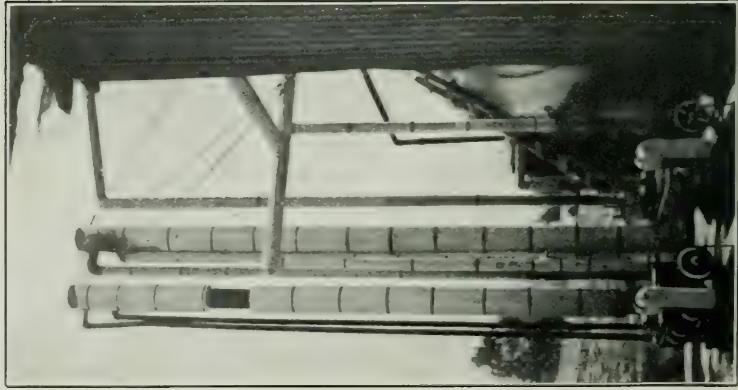
Two distinct types of interchangers are being used in absorption plants, the tubular and double pipe, or the jacketed line. Each type has a number of practical applications.



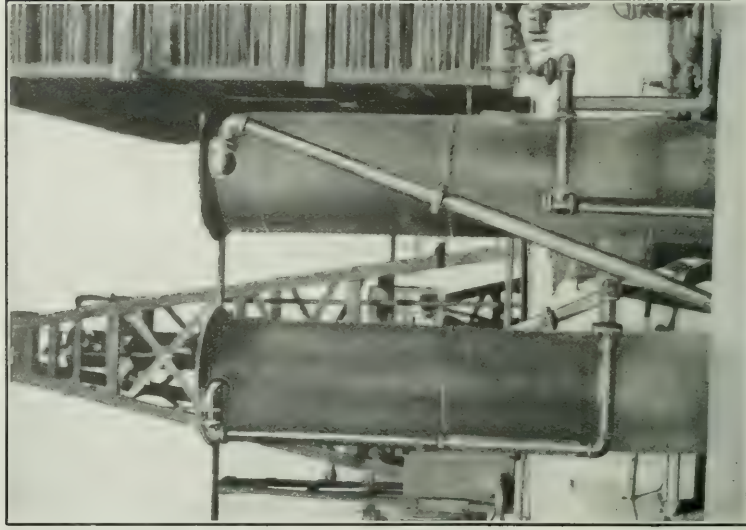
A. HEAT INTERCHANGERS, FIVE IN SERIES, SET HORIZONTALLY; SHOWS PIPING BEFORE INSULATION HAD BEEN APPLIED.



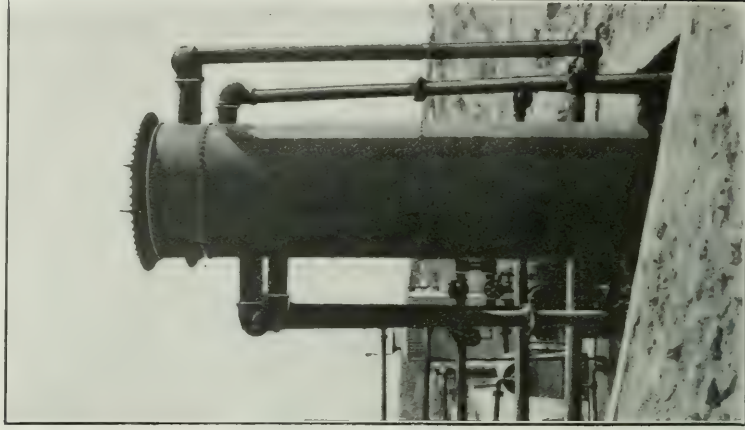
B. HEAT INTERCHANGERS SET VERTICALLY, SEVEN IN SERIES, WITH INSULATION IN PLACE. OUTSIDE PIPE IS 18 INCHES BY 18 FEET; CONTAINS 31 TWO-INCH TUBES, 16 FEET LONG.



A. TWO VERTICAL INTERCHANGERS IN SERIES, 8 INCHES BY 20 FEET IN SIZE; 1-INCH TUBES, 18 FEET LONG. NOTE SECTION WITHOUT INSULATION.



B. VERTICAL TUBULAR INTERCHANGERS, 36 INCHES BY 19 FEET HIGH, CONTAINING 127 TWO-INCH TUBES, 16 FEET LONG.



C. END VIEW OF INTERCHANGER INSTALLATION SHOWN IN PLATE XII, B.

Plate XII, *A*, shows two interchangers in series; they are made of 8-inch pipe 20 feet long with 1-inch tubes set vertically. Plates XII, *B*, and XII, *C*, which show two vertical tubular interchangers 36 inches in diameter, placed in series and uninsulated, gives a good idea of the piping and connections.

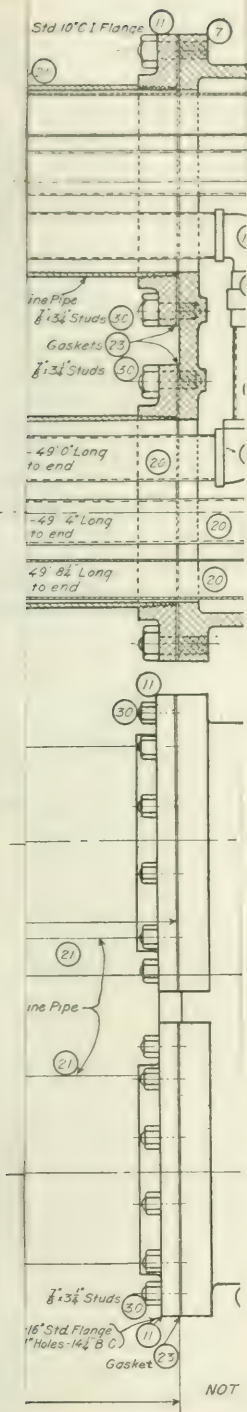
Tubular interchangers of the second type, such as the one shown in figure 20 are used somewhat, the units being so constructed and baffled that the oils make two or more passes through or over the different sets of tubes. In figure 20 the tubes shown are so baffled as to cause six passes of the oil through them and the drum is so baffled as to cause two passes of the oil over the tubes. In this unit the heat exchange obtained is between 7 and 10 B. t. u. from each square foot of surface per hour per degree of mean difference in temperature. In either of the two types of tubular interchangers described, it is difficult to obtain the maximum exchange of heat from a given area of tube, because of the large diameter of the tubes and the consequent low velocity of flow. Although this type may give the same outlet temperature as one that is more efficient, the surface required will be larger than in interchangers of the double pipe or jacketed line construction, and construction and maintenance will be much more expensive.

JACKETED LINE OR DOUBLE-PIPE INTERCHANGERS.

Two types of double-pipe or jacketed line interchangers have been developed. One has a number of small pipes within a large pipe and resembles the tubular type first discussed, except in length and in flow velocities. The other has a single pipe inside of another pipe large enough to give the space desired for the flow of oil.

An exceedingly good example of the first type is shown in Plate XIII and figure 21; in it crude oil is being heated on its way to the stills and residuum from the stills is being cooled on its way to storage. The necessary area of heat-exchange surface is obtained by using as many units as the quantity of oil being treated requires. The rate of heat transfer is 20 to 22 B. t. u. per square foot, per hour per degree of mean temperature difference.

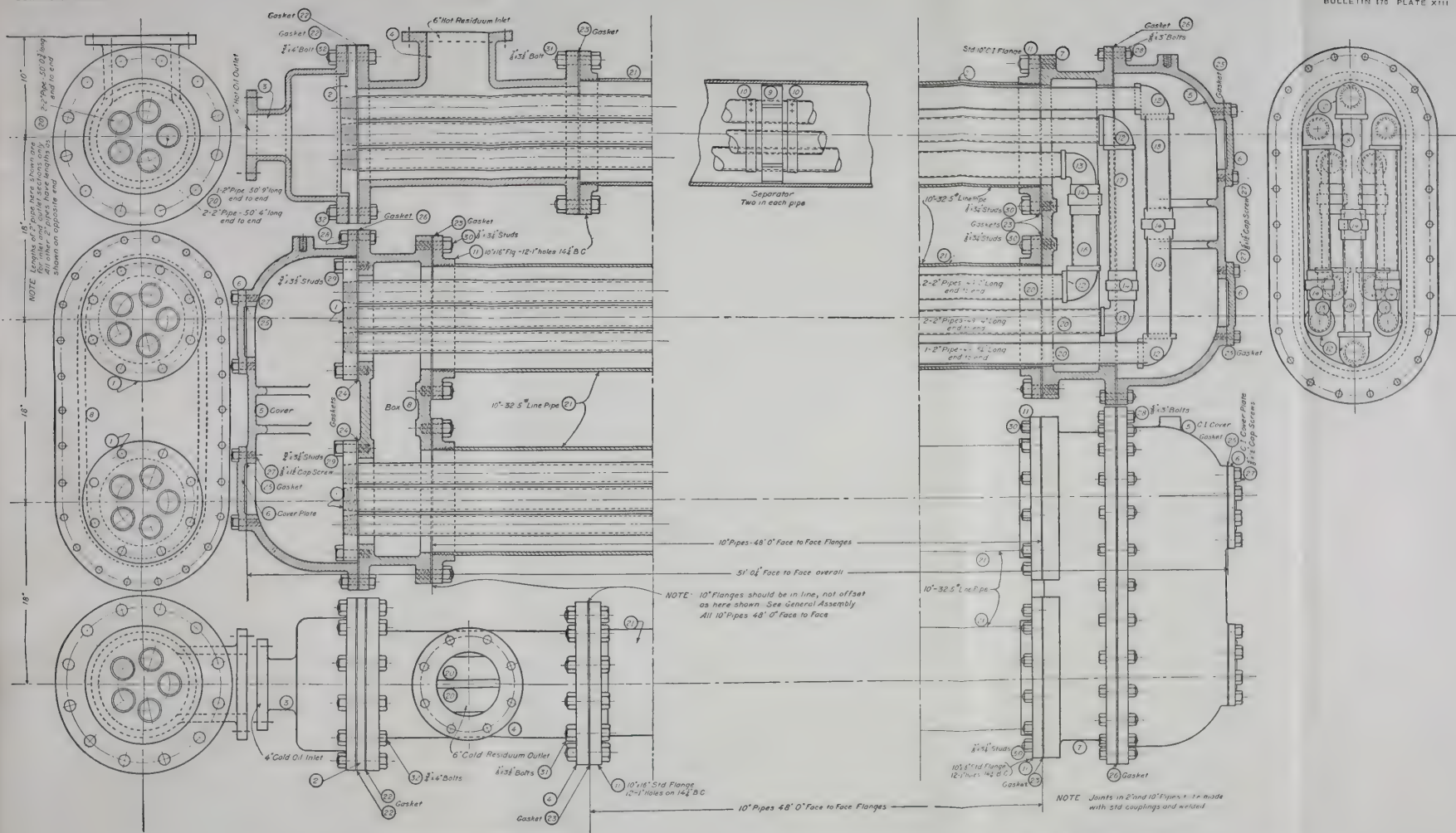
As an example of the effect of velocity of flow, J. M. Wadsworth, petroleum engineer of the Bureau of Mines, says that "in an installation similar to this the quantity of oil circulated in both directions was doubled, thus doubling the velocity, while the temperature of the oil discharged in each direction remained practically the same. The rate of transfer must necessarily have been increased 100



SECTION B-B ON

RES IN PARENTH

nech elbow (60); 13, 2-inch
ket, 17-inch (4); 23, gasket
lts (24).



CONSTRUCTION DETAIL FOR HEAT INTERCHANGER USED AT AVON REFINERY. IN THE FOLLOWING LIST, THE FIGURES IN PARENTHESES REFER TO NUMBER REQUIRED.

1, Cast-iron plate (10); 2, cast-iron plate (2); 3, reducer (2); 4, tee (2); 5, cover (19); 6, cover plate (38); 7, box, open end (10); 8, box, closed end (9); 9, separator (40); 10, stop (80); 11, 10-inch flange (40); 12, 2-inch elbow (60); 13, 2-inch ell (10); 14, 2-inch union (60); 15, 2-inch nipple, 6 inches long (20); 16, 2-inch nipple, 13 inches long (20); 17, 2-inch nipple, 9 inches long (10); 18, 2-inch nipple, 10 inches long (10); 19, 2-inch pipe, cut to lengths shown (100); 20, 2-inch pipe, cut to lengths shown (20); 21, 10-inch pipe, cut to lengths shown (20); 22, asbestos fiber gasket, 17-inch (4); 23, gasket, 11-inch (10); 24, gasket, 12-inch (18); 25, gasket, 8 $\frac{1}{2}$ -inch (36); 26, gasket, 17 $\frac{1}{2}$ by 30 $\frac{1}{2}$ inches (10); 27, cap screws, $\frac{1}{2}$ by $\frac{1}{2}$ inches (304); 28, $\frac{1}{2}$ by $\frac{1}{2}$ inch machined bolts (494); 29, $\frac{1}{2}$ by $\frac{1}{2}$ inch studs (144); 30, $\frac{1}{2}$ by $\frac{1}{2}$ inch studs (480); 31, $\frac{1}{2}$ by $\frac{1}{2}$ inch machined bolts (24); 32, $\frac{1}{2}$ by 4 inch machined bolts (4).

per cent to allow all temperature to remain the same while the flow of oil was doubled."

Interchangers constructed of two pipes, one within the other, give a high rate of heat exchange. One built of 3-inch pipe inside of 6-inch pipe, shown in figure 22, having a radiating area of 455 square feet, or 0.1 square foot per gallon per hour, raised the temperature of the oil 80° F. Another interchanger using 1,600 feet of 2½-inch pipe inside of 3¾-inch casing, a radiating area of 0.28 square foot per gallon per hour, raised the oil 60° F.

Table 4 following gives the sizes, capacities, and area of the different types of heat interchangers used in absorption plants for oils of practically the same character from stills at nearly the same temperatures.

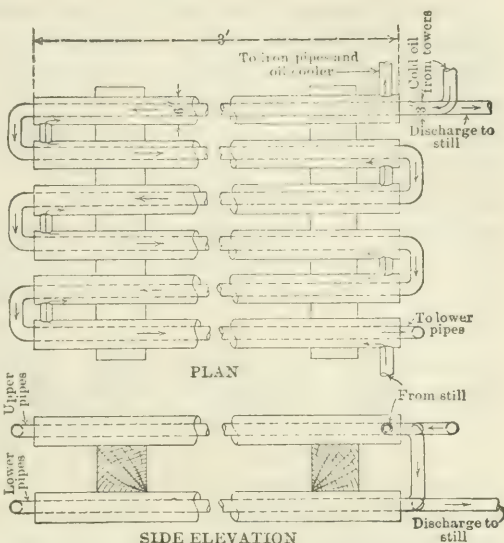


FIGURE 22.—Continuous double-pipe counter-flow interchanger.

TABLE 6.—Transfer area per gallon per hour in heat exchangers.

Plant No.	Oil flow per hour.	Type.	Interchanger.					Transfer area.	
			Outside tube.		Inside tubes.				Total area.
			Diam-eter.	Length.	Num-ber.	Diam-eter.	Length.		
	Gallons.		Inches.	Feet.		Inches.	Feet.	Sq. ft. per gal. per hr.	
1	13,300	Tubular.....	30	9	357	1	7½	a 4,362 0.328	
2	8,500	do.....	18	18	31	2	16	a 2,594 .226	
3	3,750	Double pipe.....	4	1,520	-----	2½	1,600	1,050 .28	
4	1,250	Tubular.....	36	19	127	2	16	2,120 1.606	
5	4,941	Double pipe.....	66½	504	-----				

a Ten units, five in series; later changed to 14, 0.42 square feet per gallon.

b Casing.

CONCENTRIC PIPE HEAT EXCHANGERS.

An unusual but entirely practical exchanger in use is made by fitting pipe concentrically within larger pipe, the pipe diameters selected being such that the area of the cross section through which

oil flows in each pipe being as nearly equal as possible. As the oil being cooled and that being heated occupy alternate pipes, each of the fluid streams is effective toward both the inside and outside of the coil, so that loss of heat by radiation to the air is lessened.

In determining the number of interchangers to be erected, operators use as factors various constants, such as 0.324 to 0.375 square feet of surface per gallon per hour in the unbaffled or single-pass type of tubular interchanger. In a plant using 1-inch tubing inside of a 30-inch pipe the factor used is 1.4 linear feet of 1-inch pipe per gallon per hour; at another plant which uses 2-inch tubing inside of 18-inch pipe the factor is 0.68 linear feet per gallon per hour. In double-pipe interchangers of both single and multiple pipe construction, such as 2-inch inside of 3-inch, 0.25 to 0.30 square feet of radiating area per gallon per hour is giving satisfactory results.

In the statement just made the main point has been the rate of heat exchange, because that is the only criterion for comparing the various types of interchangers at different plants, whereas the function of an interchanger is to heat the oil going to the still as much as possible in order to save fuel and to cool correspondingly the outgoing oil in order to save cooling surface and water. The rate of heat transfer is a factor of first cost rather than of overall efficiency, for the incoming and the outgoing oil may be brought to the same temperature regardless of the rate of transfer by allowing enough transfer surface. First cost should be considered, however. The writer has seen an exchanger having a transfer of 1 to 2 B. t. u. that was estimated to have cost \$50,000, whereas another having the same oil capacity but a transfer rate of about 20 B. t. u cost \$4,000.

If the hot oil coming from the still is cooled as much as possible by radiation and by transfer in reducing the temperature of the oil going to the still to within 40° F. of the still temperature, the work done by the interchanger is satisfactory, regardless of the required number of feet of radiating surface. With equal results, the factors controlling design are first cost and cost of upkeep.

Rather than use hot oil pumps to obtain high velocities in the exchangers, some operators prefer to allow the oil to flow by gravity, and in order to get the desired temperatures at both ends they increase the areas of the contact surface or use more interchanger units. This method has the advantage of relieving the pump that forces oil to the still, of overcoming the friction due to high velocity, and of lifting the oil into the still or the stone tower.

Refinery operators who have had broad experience and technical training say without reservation that heat interchangers of the type and general construction shown in figures 20, 21, and 23 are the

most efficient and the cheapest to build, operate, and maintain. The coils require only standard fittings and can be kept in repair by refinery employees.

If the oil being cooled is in the outside pipe, as shown in the figures, there is no need of insulation, for the radiation loss makes practically no difference in the final temperature of the oil being heated and tends to lower the temperature of the oil being cooled.

In absorption plants the problems of heat exchange are less complicated than in refining practice because the temperatures are more uniform, the quantities of oil circulated in each direction are nearly equal, differing only 6 or 7 per cent, and the specific heats and viscosities are also nearly equal. In fact, the factors named are so nearly equal that the inequality may be disregarded and the variations in heat-exchange areas and in sizes of pipe can be compensated by using a reasonable factor of safety.

Daily records of interchanger temperatures from six plants, in different parts of the country, and taken at different seasons, follow:

TABLE 7.—Oil temperatures to and from heat exchangers.

Points at which temperatures were taken.	Temperatures in plant No.—					
	1	2	3	4	5	6
Unsaturated oil from interchangers.....	° F. 144	° F. 150	° F. 153	° F. 147	° F. 138	° F. 130
Saturated oil entering interchanger.....	° F. 64	° F. 12	° F. 6	° F. 76	° F. 102	° F. 101
Unsaturated oil from still.....	214	208	191	216	208	205
Saturated oil to still.....	150	97	140	160	170	170

^a Temperatures taken at tower discharge, from which the oil passed through a steam pump before reaching the heat exchanger.

The temperatures are not exactly comparable, as they were not taken at corresponding points in any two plants. Some plant operators take the temperatures of the oil before it reaches the dephlegmating columns; others take the temperature afterward. Moreover, temperatures in the table were read at different seasons, the figures in the first three columns being taken in winter and those in the last three in summer. At plant No. 6 the condensed water from the still passed through one unit of the interchanger, replacing oil. This method undoubtedly economizes heat, as water has twice the heating effect of oil for an equal change of temperature. Although the data in the table were taken from daily report sheets, and show figures necessary in calculating overall efficiency, they can not be used for computing the actual transfer of heat from the saturated to the unsaturated oils in the interchanger.

However, it is clear that the exchange of heat lessens fuel cost and boiler capacity, so that it is far too valuable a feature to be omitted

at any plant. Besides conserving fuel interchangers reduce decidedly the amount of water required for cooling and the amount lost by evaporation. The latter item deserves careful attention in many plants, especially in California where water costs 3 cents a barrel.

The heat saved by interchangers at the plants shown in Table 5 ranges between 22 and 77 boiler horsepower. Using 50 cubic feet of gas per horsepower hour the interchangers save between 26,000 and 95,000 cubic feet of gas a day.

RADIATOR INTERCHANGERS.

Although the radiator type of heat-interchanger has not proved a success a short description of it may be of interest. On its way to or from the still the oil is passed in series through the coils of a steam radiator made of cast iron or pressed steel. These radiators are placed in light-weight, tightly closed steel boxes, the oil in the steel boxes flowing over and under baffles countercurrent to the flow in the coils. The greatest fault found with this type of coil is that the radiators are not built to withstand pressures above 15 pounds. At one plant a coil of this type burst and the oil was ignited, causing the death of one of the operators. The unit was dismantled and a double-pipe coil used in its place.

In general, it has been found that about 0.30 square feet of radiating surface per gallon per hour is enough in interchangers of the double-pipe continuous-coil type and about 0.40 in the multiple-pipe units. As velocity of flow is important in heat exchange, the continuous double-pipe coil appears to have the greater advantages in both construction and operation.

STILLS.

Stills of a number of different types have been installed at absorption plants, most of the types being those used in refineries for somewhat similar operations. The action desired is practically the same as that in topping plants, for only two products are made—the gasoline fraction, which is vaporized, and the residuum, or absorption oil, which remains in the still.

Usually the oil used for absorbing has an initial boiling point of 450° F., or more, and the end point of the gasoline absorbed is 300° F., so that the gap between the two temperatures is not less than 100° F. Although this condition greatly simplifies the operation of the still, it is impossible, even in a steam still, to remove all of the gasoline from the oil without the gasoline vapors carrying a small fraction of the heavier oil from the still. This fraction is taken up by the action of partial pressures and of other physical

principles: moreover, small particles of the oil are carried mechanically with the gasoline vapors and the steam rising from the surface of the oil in the still.

Separation of this small content of heavy oil from the vapors is accomplished by fractional cooling. To determine and maintain the proper temperatures in still, still towers and cooling coils is a most vital matter, and one with which many operators have the most difficulty. Steam stills with either closed or perforated coils, or both, are the simplest and the most used.

STEAM STILLs.

Figure 23 gives details of a steam still that has proved satisfactory to many operators. From the heat interchangers the oil with a temperature of 160° F. to 170° F. rises through the 4-inch line to the top of the still tower, and is discharged over the stones, tile, or baffles, with which the tower is filled. As the figure shows, the tower is set over the still; it is connected to the still by two large vapor lines that enter near the bottom, and by an oil outlet from the bottom of the tower to the top of the still.

Oil from the intake at the top divides over the baffling of wall-tile, or stone, and flows downward through the tower countercurrent to the vapors rising from the still. The vapors pass from the top of the tower to the cooling coils through the inclined 8-inch pipe.

The object of the tower is to condense and carry back into the still the fractions of heavy oil that are vaporized or are mechanically entrained with the gasoline and steam vapors; to liberate the vapors that come from the oil at the temperature it has acquired in the interchange; and also to collect the heat produced by the condensation of these heavy vapors, thus reducing the work required of the steam in the still in the same way as the interchanger reduces the necessary amount of heat.

This type of tower is justly criticized by California refiners on the ground that the heat interchange itself is too small to be of decided value. Moreover, their long experience with topping plants has proved that the cooler incoming oil has a strong tendency to absorb the light vapors as well as to condense the heavy one; hence the practice of refiners, in order to eliminate the absorbing action, to remove the vapors from contact with the the heavy or incoming oil as soon as possible.

These refiners suggest that any heat interchange between vapor and oil should be made with the oil in double-pipe coils or in tubes and out of contact with the vapors. Also, if it is desired as is considered the best practice, to remove the vapors from the hot oil in a

tower, to spread the oil in thin sheets in some type of apparatus, allow the vapors to come off, and remove them as soon as possible from contact with the oil. This practice is followed most perfectly in

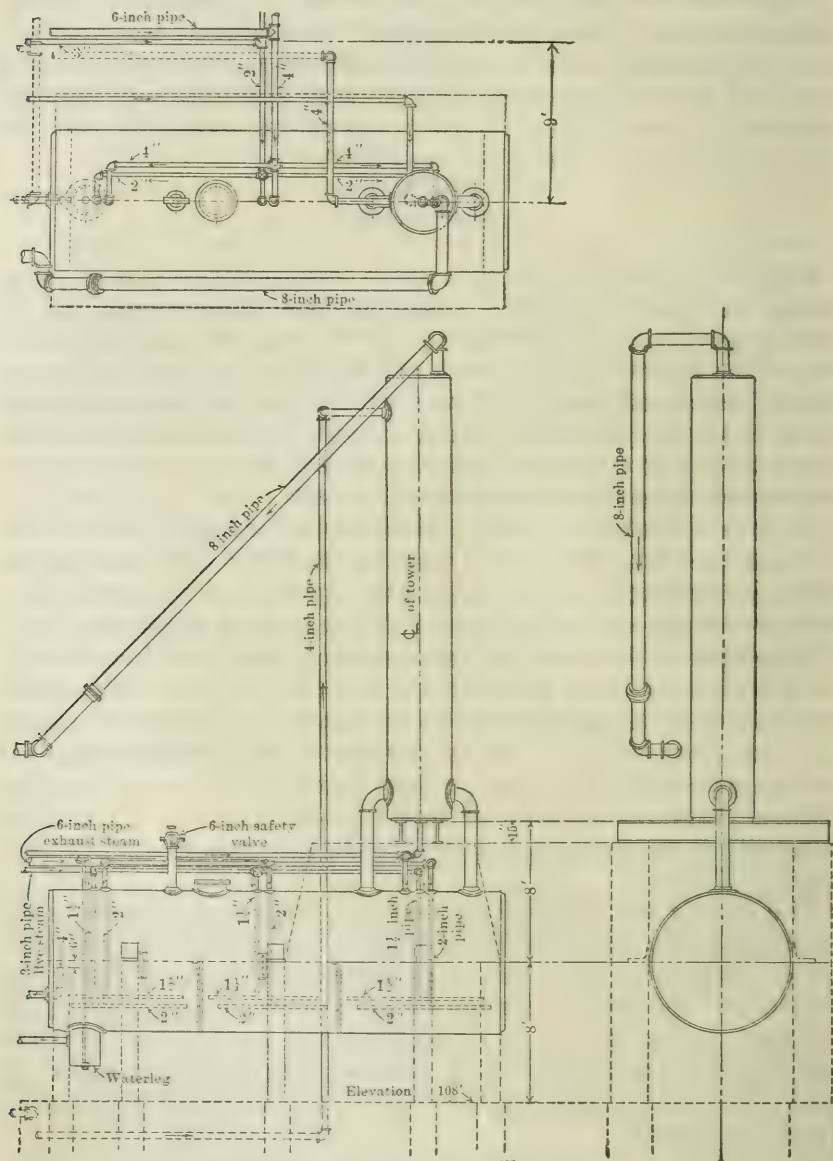


FIGURE 23.—Detail of steam-still installation.

the Trumble type of fire-still tower. A dephlegmating action, such as is used in rerunning "tops" to obtain narrow cuts of the different fractions, is neither necessary nor desirable in absorption practice.

Plate XIV, *A* shows this type of stone tower. When this tower was full of stone the absorbing action proved much too great, consequently more than half of the filler was removed.

Following the example set by one of the largest and most successful absorption plants, many operators have placed towers of this character over their stills, and the practice is now general. The writer believes stone towers of this type are not only unnecessary but are prejudicial to the action desired and that a careful study will lead to many changes in the design and operation of stills in absorption plants.

Plates XIV, *B*, XV, *A*, and XV, *B* show stills and towers of the type described above.

In these stills the temperature of the incoming oil is often as high as 160° or 170° F. and at times 190° F., depending on the heating effect obtained in the interchangers. As the oil passes through the stone tower on its way to the still it may become warmer, so that at times it may enter the still at a temperature 10° F. higher than that at which it entered the top of the tower. Oil enters a still of this type at the end opposite the discharge, passing over and under vertical baffle plates, if baffles are used, and meeting steam, from open or perforated pipes, which completes the separation of the volatile hydrocarbons.

The pressure in the stills is 2 to 5 pounds, the stills being fitted with safety valves set at this pressure, and the temperature ranges from 206° to 218° F. As an aid in heating and temperature control, many stills have closed steam coils at the bottom; through these coils live steam at any pressure and temperature may be passed to raise temperature quickly. In coils that are open or perforated exhaust steam from the pumps is often used, being discharged against the still pressure of 2 to 5 pounds at temperatures corresponding to the steam pressure. Using the exhaust steam from the oil pumps is economical when steam pumps have to be used, but when pumps driven by gas engines are used, and the steam for heating is taken directly from the boilers at the desired pressures and temperatures, the saving would appear in the quantity of gas used for power. This saving would be an object to companies that sell gas.

In stills of this type the oil level is maintained at about half of the height of the still by an open discharge pipe, or by any one of the fluid-level regulators now obtainable, the oil flowing to the heat interchangers.

In stills baffled as those shown by figure 23 (p. 58) the oil is forced to flow over and under each baffle in series on its way to the discharge, and provision must be made for water, condensed from the steam in the still, to flow along the bottom of the shell and to be drained away. Drainage is usually effected through perforations in the baffles near the still bottom. In the still shown by figure 24 the water

leg is used to trap the water and discharge it to one of the series of seven heat interchangers; in other plants the water goes to the hot well and is used to feed the boilers.

Stills of this type are of such diameter and length that when in full operation the oil they contain and treat, is approximately the amount circulated through the system in one hour; in other words, the heat treatment in the still takes one hour.

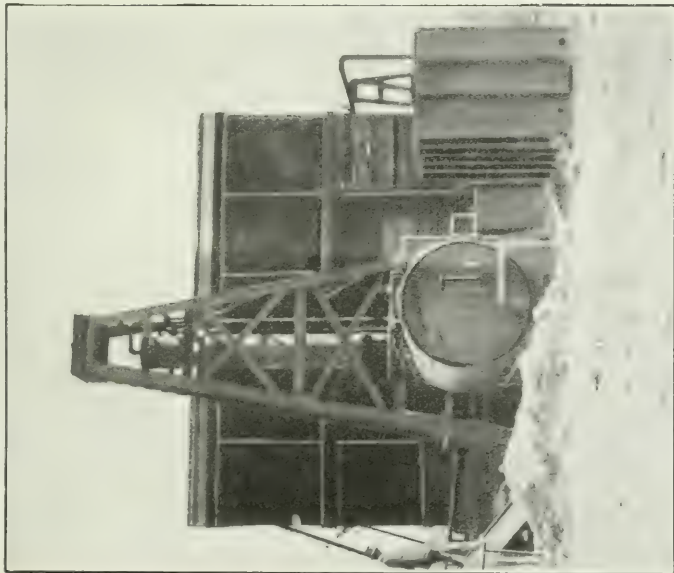
VERTICAL STILL.

A large operator in western Pennsylvania uses a vertical steam still of quite different type, with notable success. The still has no tower, but instead a vapor and oil heat interchanger. Oil from the interchanger at a temperature of about 160° F. passes through the tubes of a preheater of the type used in heating boiler feed-water with exhaust steam or hot gas. The still vapor at 212° F. passes from the top of the still to the heater drums which surround the tubes carrying the oil; the oil is warmed and the vapors cooled, a large part of the absorption oil and steam carried over with the vapors is condensed, and the particles of oil carried mechanically can settle. Thus the interchanger acts as an auxiliary condenser and separator or "knock-out box." The condensed oil and water are separated from the vapors by a trap similar to a steam trap and are discharged to the still, while the vapors are conducted directly from the top of the preheater to coils cooled by air and water. This arrangement eliminates the auxiliary water-cooled coil, used in many plants, which is maintained at a temperature of approximately 185° F. to separate the heavy oil and water.

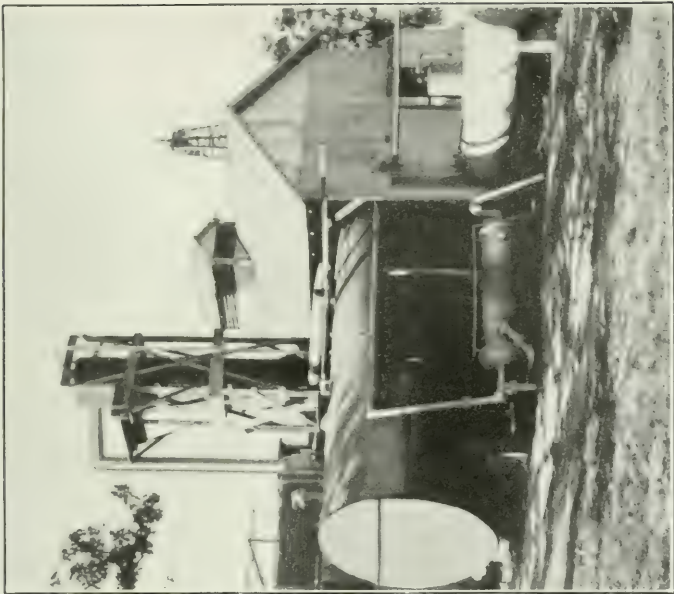
The steam still used is a boiler shell set vertically and filled with banks of steam radiators; in flowing over these the oil is heated and gives up the gasoline vapor. An open coil at the bottom introduces steam to simplify the heat control and aids the separation of the vapors. The steam in the radiators has a pressure of 10 to 16 pounds and a corresponding temperature. In a day the still handles easily 126,000 gallons of oil containing about 2 per cent of gasoline.

HORIZONTAL-PAN STILL.

Figure 24 shows a still of the horizontal cylindrical type, 5 feet in diameter and 16 feet long. Instead of the oil being allowed to lie in the still at a height of about half the diameter, it is discharged into a shallow, slightly inclined pan, 5 inches deep; in this the oil runs slowly toward the opposite end of the still where it is discharged through an overflow pipe 1 or 2 inches above the pan bottom to the next pan below which slopes in the opposite direction. Four or five such pans are placed in the still shell. On the bottom of each pan is a continuous return-bend coil of 1-inch pipe 210 feet long,



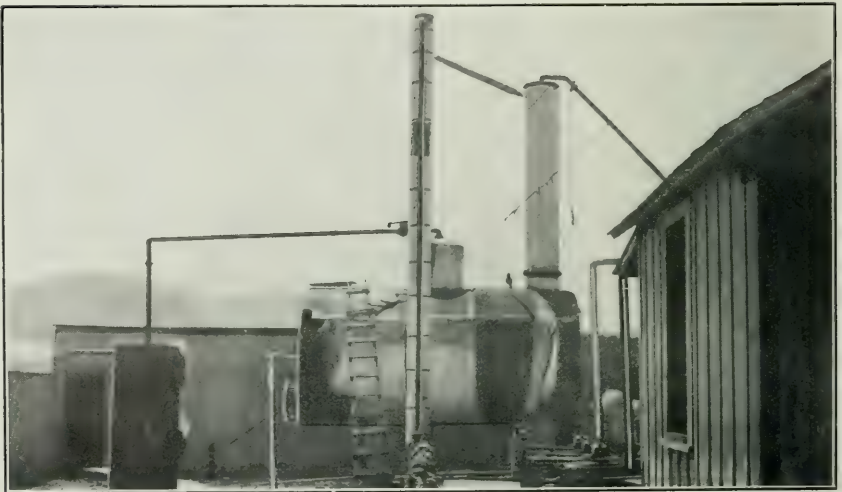
A. STILL, AND STONE TOWER.



B. STEAM STILL WITH TOWER SUPPORTED ON SEPARATE BASE; TREAT 10,000 GALLONS PER HOUR.



A. STEAM STILL, 8 BY 24 FEET; TREAT 5,000 GALLONS PER HOUR; ALSO SHOWS AUXILIARY SUBMERGED COIL AND "FINAL" COIL.



B. STEAM STILL, 6 BY 12 FEET IN SIZE; CAPACITY 1,000 GALLONS PER HOUR.

over which the oil travels. Steam intakes and discharges for each coil are connected to headers outside of the still shell, and are controlled by valves. In the bottom of the still is a perforated steam

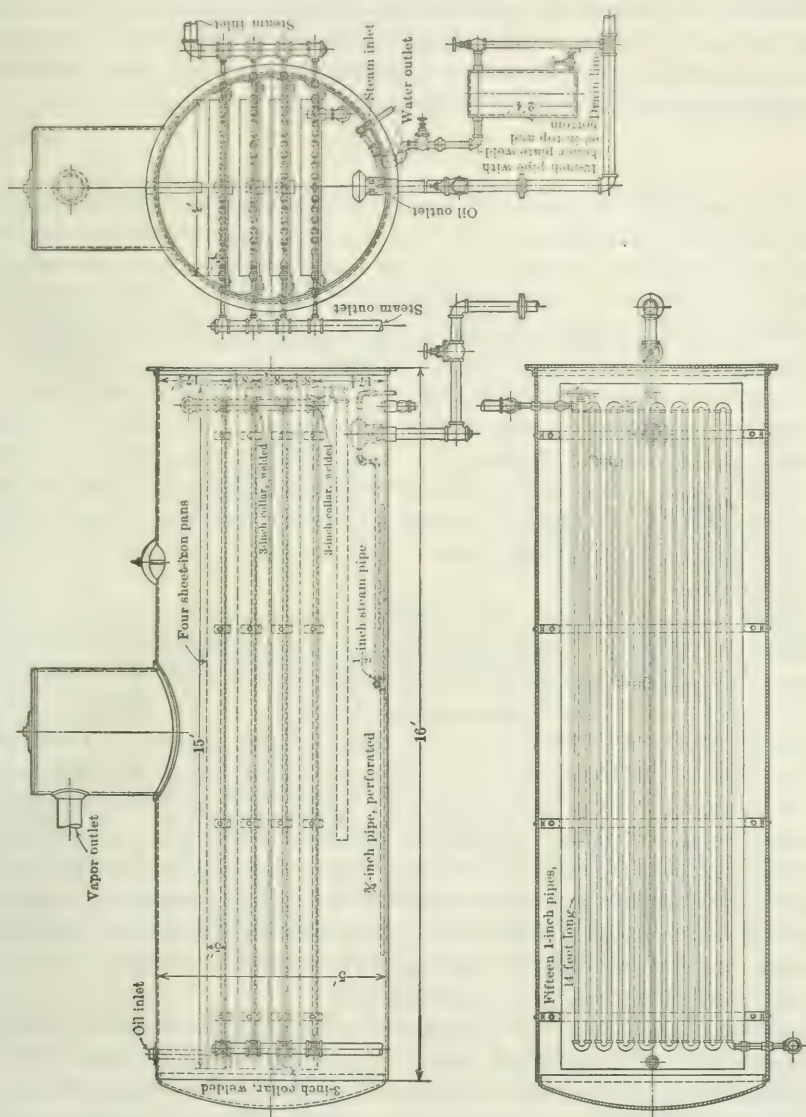


FIGURE 24.—Pan type of steam still.

line that is kept covered with oil to a depth of 6 to 12 inches by a float, as shown, or by a fluid-level regulator. The steam discharged into the oil removes the last gasoline vapors and helps to carry all of the vapors out of the still to the vapor lines.

Such a still is simple to erect and to run, and has an exceedingly large capacity in this service. The still shown in figure 24 has a capacity of 5,000 gallons per hour when using steam at 90 pounds pressure: it heats the oil quickly, the gasoline vapors being liberated in less than 20 minutes after the oil enters the first pan. The large-diameter stills previously described require an hour, and often two hours, to separate the gasoline from the oil.

FIRE STILLs.

Fire heated stills and stills heated by both fire and steam are used at the absorption plants, but they are not common and at present are considered good practice, as the control necessary in separating the two factions without overheating is not easily obtained where a still or the piping containing the oil is subject to open flame or to direct heating in combustion chambers.

In steam and fire stills the oil is placed in the still shell over an open fire or over the combustion chamber of a fire box. The hot gases strike directly against the still shell, heating the oil inside. A perforated steam coil is placed within the still near the bottom, to heat the oil and help the escape of vapors, and also to agitate the oil so as to keep the temperature near the bottom sheets of the still from rising unduly.

One still heated only by fire was seen by the writer, the heating being done in 4-inch pipes in continuous return-bend coils set near the top of the combustion chamber of the open fire box. The oil always was circulated through the coils in an upward direction in order to avoid the formation of gas pockets. From the last pipe of the top coil the hot oil went to the top of a tower called a separating tower, or evaporator, where it passed in thin sheets over a series of baffles, so that the gasoline vapor had unlimited opportunity to escape from the oil. The vapors collect under hoods and flow through perforated pipes to a header, from which they go to the water-cooled condensers. At the time of the writer's visit, this plant was having difficulty in controlling temperatures so as to prevent overheating and loss of production.

Because the steam induces the vaporized light hydrocarbons to separate from the oil, and because the temperature of steam at low pressures (2 to 5 pounds) is that best suited to distilling in the open or perforated coils used in absorption plants, the writer believes that fire stills will never become general in absorption practice.

HEAT NECESSARY FOR DISTILLING.

Probably the most common of the serious errors, in plant design hitherto has been the calculation of the heat or steam requirements for distilling.

By using the constants given below, or those that are similar, the theoretical heat requirements can be calculated, but the efficiency of the still in using heat is given as 80 per cent, whereas in practice the efficiency is practically never more than 40 per cent, and 30 per cent is a better figure to use in plant design. This figure allows some leeway for seasonal changes in temperature and for changes in quantity of oil circulated on account of variations in the quantity of gas treated.

Constants sometimes used in calculating heat for distilling.

One boiler horsepower.....	B. t. u. _	34,000
Latent heat of gasoline.....	do _	100
Specific heat of "mineral seal oil".....		0.50
Specific heat of gasoline.....		0.58
Weight of "mineral seal oil" per gallon.....	pounds _	7.00
Weight of gasoline per gallon.....	do _	5.5

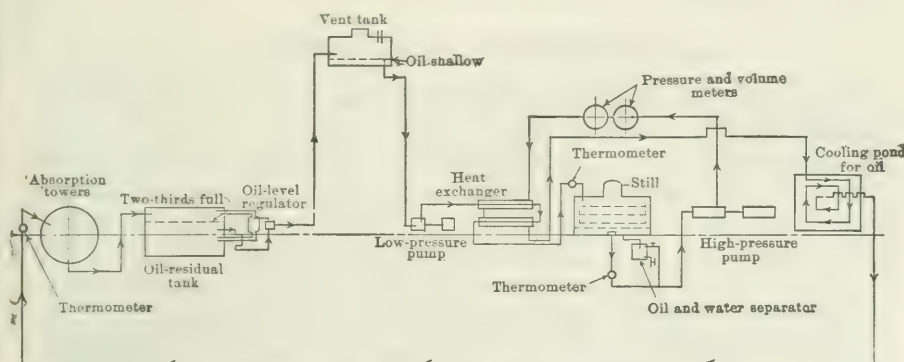


FIGURE 25.—Oil path in an eastern refining plant.

From refineries treating somewhat similar oils in steam stills the heat used was reported as 1 boiler horsepower per barrel of distillate produced per hour with open steam stills and $2\frac{1}{2}$ to 4 boiler horsepower for each barrel of product per hour with closed steam coils inside the stills.

From the stills and interchangers the oil at 80° to 140° F., goes to the high-pressure pumps, thence to the water-cooled coils, which reduce the temperatures as low weather conditions permit, and thence to the absorption towers. Figure 25 shows the complete circuit of the oil in one of the large Eastern plants.

TIME OF CIRCULATION OF OIL.

The total time required for any given particle of oil to make a complete circuit of the absorption plant varies greatly, but depends mostly on the time required to pass through the stills, interchangers,

and weathering tanks because there are the points where oil is held in considerable volume and its velocity slow. Three to four hours is probably a fair estimate of the average time of a circuit in usual practice, being more at some plants and less at others. The total quantity of oil in use at any one time is controlled in the following way: Assume that a plant treating a given quantity of gas requires 4 gallons of oil per 1,000 cubic feet of the gas and 204,000 gallons for the gas passing through the plant in 24 hours. Then the oil pumped through the circuit would be 8,500 gallons per hour, and if this oil required 4 hours to travel through the circuit, 4 times 8,500 or 34,000 gallons of oil would always be in active circulation. If three hours were required, 25,000 gallons of oil would be in use, the oil making 8 complete circuits each 24 hours.

Usually more or less tankage is provided for oil stock not in actual use, to allow buying oil in car lots and having enough always on hand to make up any loss or to meet changes in plant functions, such as an increased flow of gas.

TREATMENT OF STILL VAPORS.

The vapor, whether coming from the stone towers, the vapor-heat interchangers, or directly from the still with no auxiliary cooling at all, contains not only the gasoline vapors, but also gases liberated from the oil by the heat and steam in the still, water vapor from the steam used, and small portions of the absorption oil itself, the latter probably both as vapor and as finely divided particles of liquid.

At this point a clean separation of these four constituents is made by fractional cooling; that is, by reducing the temperature of the vapors in steps, or stages, and removing the products precipitated at the temperature in each stage. The order of separation is naturally reverse to that in distilling, the constituent of highest boiling points separating first.

As in distilling, however, any one cut of distillate, or any one member of the mixture of vapors, can not be perfectly separated at any given temperature, but portions of fractions of both higher and lower boiling points will come down with it. The liquid precipitated, or condensed, from the vapor depends on the vapor pressure of that particular component under the existing conditions of temperature and pressure.

SEPARATING OIL, WATER, AND GASOLINE.

RERUN METHOD.

Two methods are used to separate such mixtures, rerunning and fractional cooling. The rerunning method consists of vaporizing and condensing from the mixture a fraction large enough to carry

with it all of the desired cut and those portions of lower boiling fractions that can not be held as liquids, drawing off the portion left, or the still "bottom," and repeating this process with the condensed portion until the product from the coils has the character desired.

FRACTIONAL COOLING.

Fractional cooling is of greater advantage in absorption practice, because the gasoline cut is the only one that must be perfectly clean. Owing to their mutual insolubility water and gasoline and water and oil separate from each other by gravity. Water is the overlapping fraction precipitated throughout fractional cooling with both the oil and the gasoline, and in each instance it is separated after condensation by settling, the oil or gasoline being floated away.

COOLING OF THE VAPORS.

PRIMARY CONDENSERS.

The vapors from the stills have temperatures between 200° and 220° F. In order to completely reciprocate the absorption oil vapors, they must be reduced to between 180 and 190° F., which is the first step in fractional cooling. This cooling and separation is obtained by one of several methods. An Eastern plant reduces the vapor temperature by heat interchange with the incoming oil and by air cooling. Air cooling is in a large uninsulated pipe exposed to the atmosphere, the oil and water condensed being separated in a steam trap and returned to the still. Air cooling when conducted in the open has the disadvantage of being uncontrollable, because of the atmospheric temperature and the wind velocity changing, causing diverse rates of heat radiation, under dissimilar temperature difference, and varying dissipation by air currents. This disadvantage may be partly overcome by housing the pipe within a still building, engine or pump room, where temperature and air currents vary less than outside and are to some degree controllable. Its successful operation speaks for itself. The size and length of pipe are the factors to be determined and these depend on the temperature necessary to make the separation and the volume of vapor being treated.

Other plants use a submerged water box coil of the usual refinery construction, the water being kept at 185° F. by an electric thermal element, as shown in figure 26, at the discharge of the smaller of the coil boxes. The condensed products, oil and water, are separated from the vapors and each other by the overflow trap, the vapors from the separating chamber flowing into the pipes leading to the second coil. Although this construction and operation are both simple and efficient, it is a question whether

the cost is warranted, although the water discharged can be used as boiler water, the condenser taking the place of a pre-heater. If gas engines were used to drive the pumps the same saving could

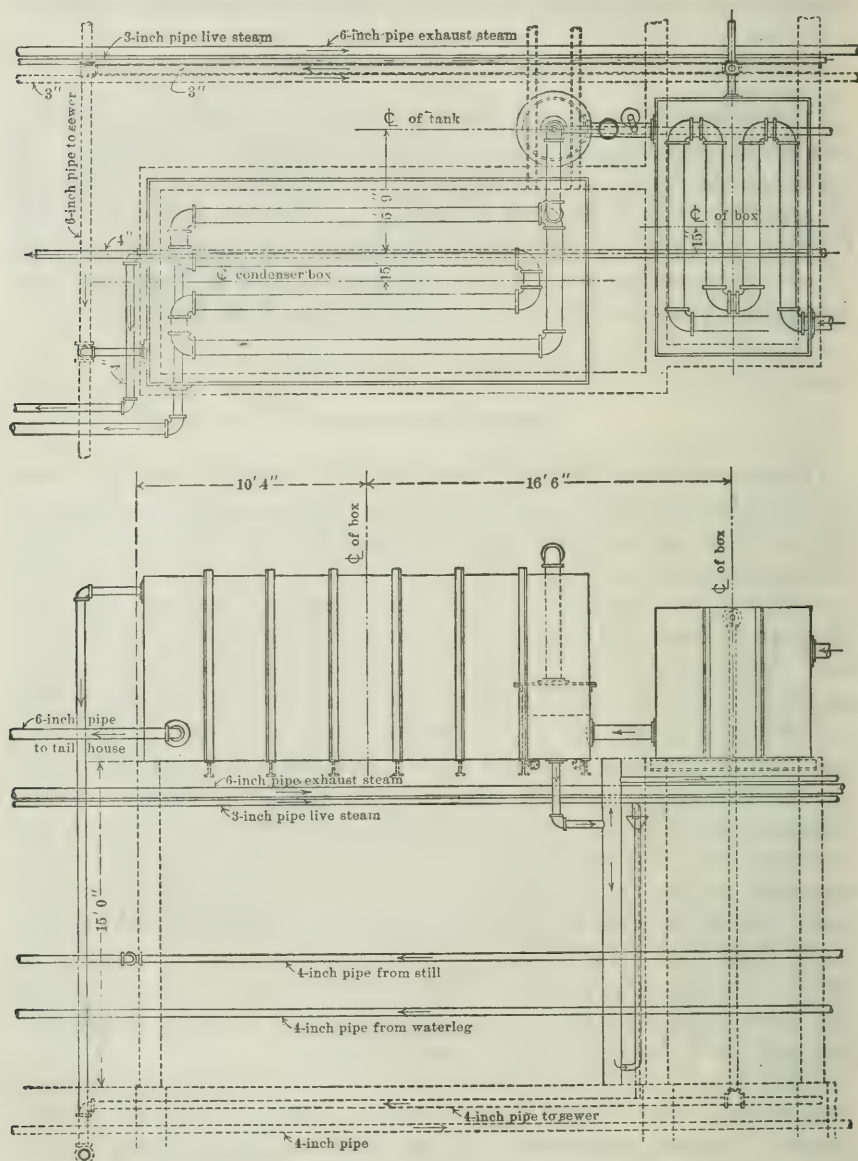


FIGURE 26.—Submerged cooling coils. Small coil is the primary condenser; electric thermal control is placed in the connection between the two boxes.

easily be made by passing the exhaust gases through the feed-water preheaters of the tubular type, but care must be taken not to have the back pressure on the exhaust too great.

At the plants visited, the areas of the first-stage submerged cooling coil of 8-inch pipe was between 2 and 2.5 square feet for each gallon of gasoline extracted from the gas per hour. Although this coil precipitates no gasoline, heat is extracted from the vapors to liquify the heavy oil and part of the water vapor at this point, and the amount will be about the same for each gallon of gasoline distilled. The factor is therefore given in terms of gallons per hour, rather than in British thermal unit equivalents.

If smaller pipes are used the area can no doubt be considerably reduced, the velocity of flow and the consequent rate of transfer becoming more rapid.

Cooling the vapors by interchange of heat with the incoming saturated oil has been discussed elsewhere. To this point cooling has precipitated all of the Mineral Seal oil and a large part of the water vapors coming from the still.

FINAL COOLING COILS.

Vapors from the first stage, or auxiliary cooling coils, whether submerged coils, heat exchanger, or air-cooled pipes, are led directly to where the second reduction of temperature, precipitating gasoline and water, takes place. Here two methods, singly or in combination, are used to cool the vapors—submerging the coils or cooling them by air and water in a louver tower. With either, the vapors at the coil intake have a temperature between 170° and 190° as they come from the auxiliary coolers.

A typical submerged coil is shown in figure 26 (p. 66). It has a radiating area of between 3.5 and 4 square feet per gallon of gasoline per hour. The reader should note that this coil, besides condensing and cooling the gasoline vapors and liquids, must also cool varying volumes of gas or vapors that do not condense, and also condense and cool any water carried as steam or water vapor past the first cooling. These last duties vary greatly with the cooling required at different times in the same plant, and are not at all comparable in different plants, as they depend on other functions and operations through the entire plant and on what hydrocarbons the gas carries to the absorbers.

In Plate XVI, A, a combination submerged coil and louver tower is shown. The coils are placed in both the box and louver. Little can be said for a cumbersome hybrid of this type.

COOLING COILS IN LOUVER TOWERS.

The second method of cooling and condensing vapors is by coils exposed to water and air in louver towers, as discussed on a preceding page in connection with the cooling of oil and in another publica-

tion^a of the Bureau of Mines. From 2 to 8 square feet of radiating surface is exposed per gallon of condensate per hour. An area of 2.5 square feet per gallon per hour has been adopted by a number of engineers for return-bend coils made of 2-inch pipe. This type of cooling is used in an absorption plant in California, where submerged coils proved an utter failure because of the hot, dry climate. Plate XVI, B, shows a louver tower of modern design in which compressed gas, still vapors, and absorption oil from the inter-

changer are cooled in small (1-inch) pipe coils in headers. Temperatures 40° F. below atmospheric are obtained in summer.

It is generally true that in hot, and especially hot, dry climates the use of a louver tower for cooling water is far the best practice. A tower may be used in two ways—either with coils supported in the tower under the dripping water, or cooling the water in the tower and then circulating it over submerged coils, the first method being the more efficient, as well as much more convenient, as all of the coils are at times subject to inspection, and re-

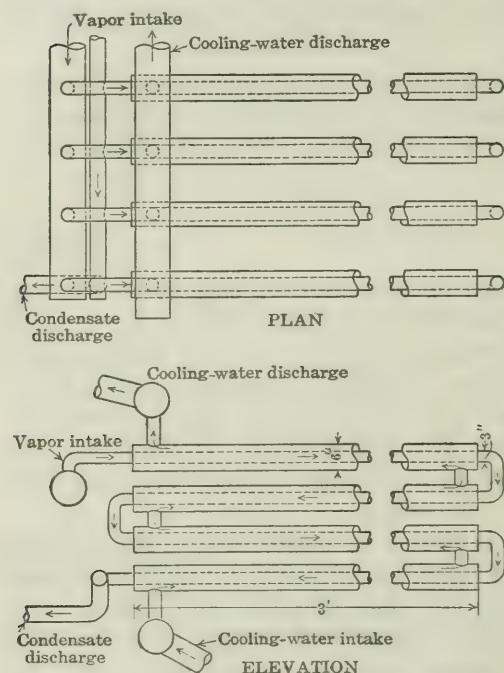


FIGURE 27.—Double-pipe vapor condenser.

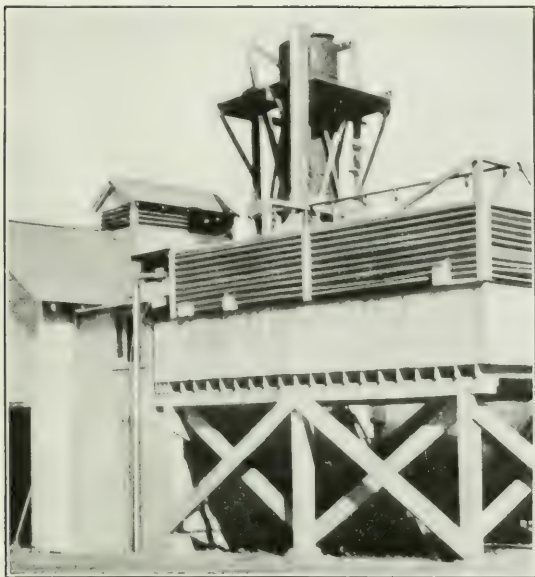
pairs can be made quickly without stopping other plant operations.

Refineries, absorption plants and compression plants in all parts of the country are using cooling coils in louver towers more and more.

DOUBLE-PIPE CONDENSER.

Figure 27 and Plates XVII, A and XVIII, A (p. 72) show an entirely different system of cooling and condensing vapors. This system uses four return-bend, continuous double-pipe coils, 36 feet long and four pipes high, with a total radiating area of 450 square feet, or between 3 and 4 square feet per gallon per hour of condensed gasoline. The vapor-intake header acts as a trap for vapors

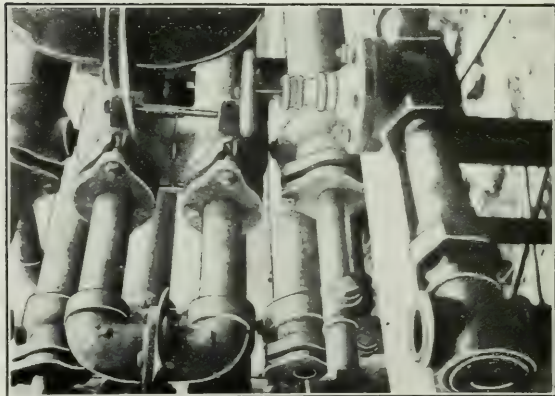
^a Dykema, W. P., Recovery of gasoline from natural gas by compression and refrigeration, Bull. 151, 1918, 123 pp.



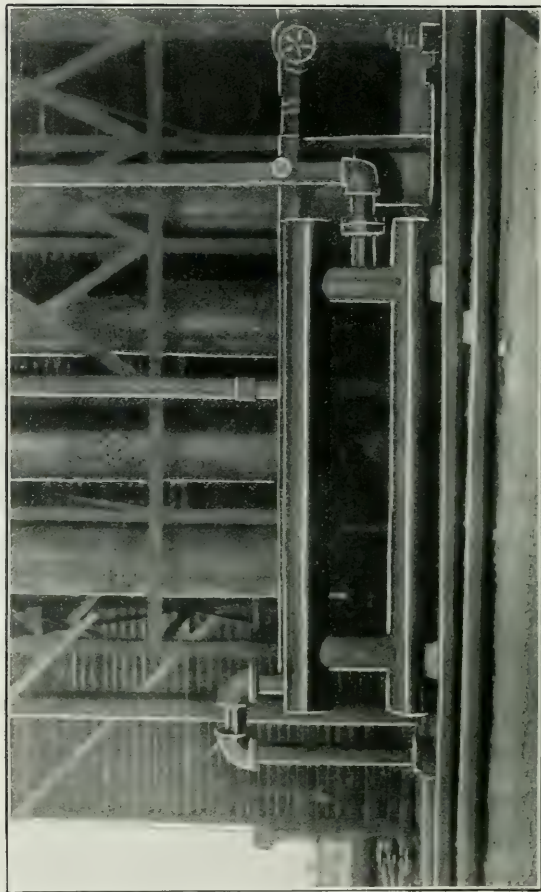
A. COMBINATION LOUVER AND SUBMERGED COIL.



B. A LOUVER TOWER OF MODERN DESIGN, ERECTED IN HOT, DRY CLIMATES.



A. END CONNECTIONS OF DOUBLE-PIPE CONDENSER.



B. TRAP FOR SEPARATING OIL AND GAS.

condensed in the line from the still. The vapors and condensate flow parallel and not countercurrent, and water flows countercurrent to them. From the coils the condensed vapors—gasoline and water—flow to the water separators and to inspection or look boxes. The cooling water flows from a header into the lowest outside pipe of each coil, flows upward, and discharges to an upper header.

SEPARATION OF GASOLINE, WATER, AND GASES.

Water, gasoline, and the uncondensed vapors and gases coming from the final coil discharge may be separated into two products—liquids and gases—at the coil outlet by connecting the end of the coil pipe to a pipe set vertically in a T connection. The pipe rising from the T carries away the vapors and the horizontal pipe leads the liquids to the water separator.

Figure 28 shows a system in which all the products are carried together through one pipe to the separating chamber, which allows the water to settle into the leg below the horizontal cylinder. This water overflows through a differential column to a waste pipe, which is fitted at the top with a funnel; the overflow pipe ends about 2 inches above the funnel to permit inspection and sampling of the passing liquid. The gasoline flows off continuously through a horizontal pipe into the inspection box, from which it goes to storage or a blending tank. The gravity of product obtained at this point ranges from 72° to 84° B.; the vapor tension is well within the shipping regulations and is often as low as 3 pounds at 100° F.

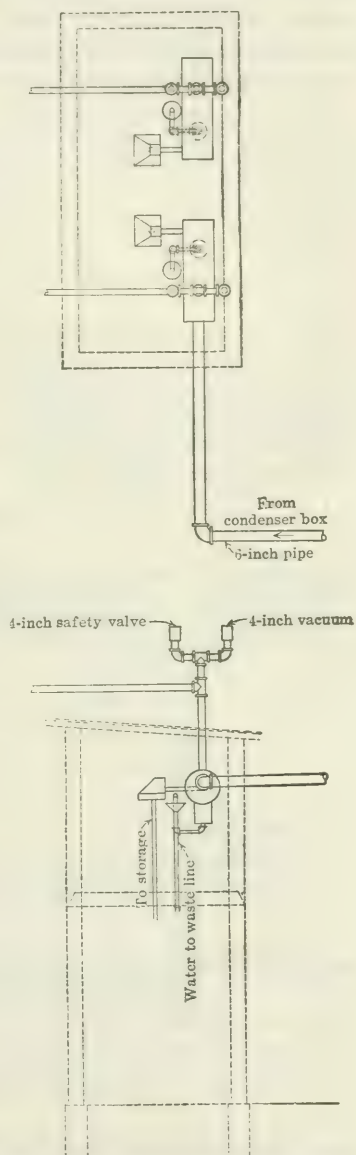


FIGURE 28.—Connections for "look box," showing method of separating vapor and water.

As the gases rising from the separator contain considerable condensable vapor they are put through a small absorption unit or are compressed and cooled in coils. In figure 29, which shows a plant using a compressor on these vapors, the pipe carrying the gases is so connected that both a pressure and a vacuum valve may be put on the line leading to the compressor. The use of these valves, set

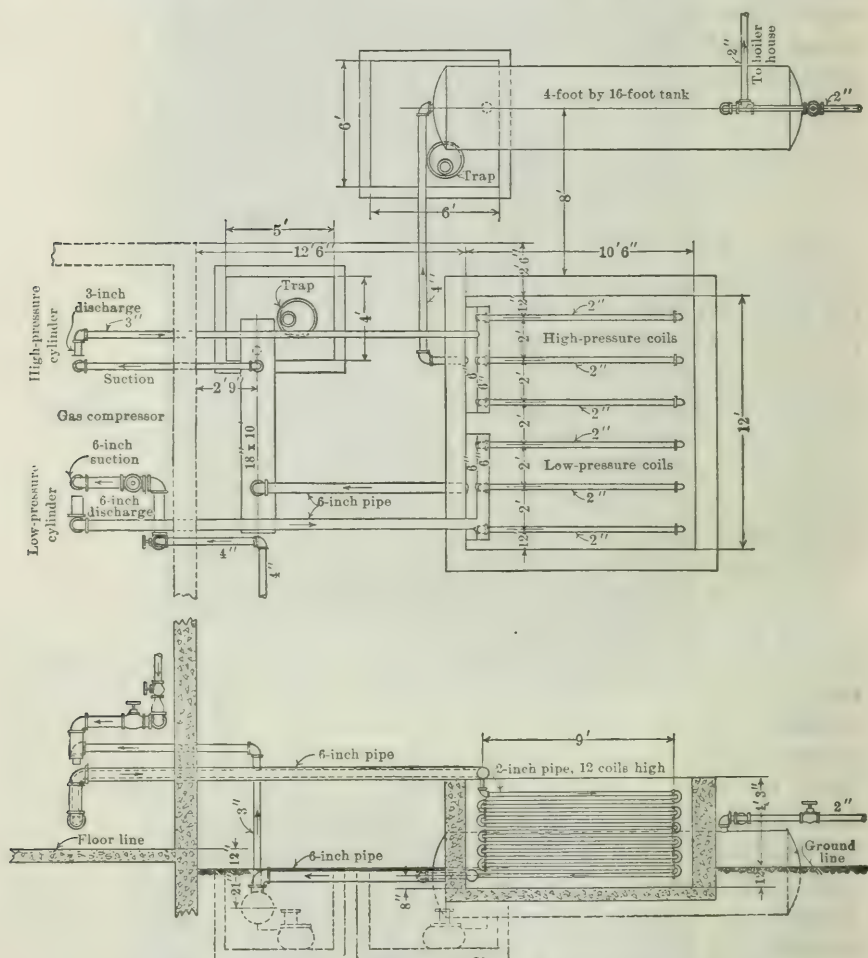


FIGURE 29.—Connections for compression coils.

to relieve pressures over 2 or 3 pounds or vacuums over 4 to 6 inches, is advisable as a safety measure. The lines are directly connected to the still which would be damaged if a high vacuum were held on it by the compressor suction at the other end of the line, and the safety valve keeps the pressure in the entire system from building up if the compressor is stopped or is unable to take the vapors fast enough.

The condensate from the compressed gas is a "wild" product unfit for shipment unblended, and is, so far as the writer knows, added to the still product in such amounts as to bring the whole to a point just within the legal requirements for shipment in tank cars. From 15 to 30 per cent of the plant product is derived from the compressed still vapors and from gas from the weathering tanks. The compression and cooling of uncondensed gases is the same as that described in other Bureau of Mines bulletins.^a To this gas is often added the gas coming from the weathering tank in which the absorption oil is first run from the towers, but as stated before, it is questionable whether these gases add materially to the net output of gasoline, whereas the compression of the gases from the still alone is known to add a valuable amount.

Figure 29 shows the coils and connections of two-stage compression units. The 18-inch by 10-inch pipe forms the accumulator of the low-pressure coil. The high-pressure product is run with the gas to the 4-foot by 16-foot high-pressure accumulator, which is a 4-foot by 16-foot riveted horizontal tank.

COST OF PLANTS.

Under conditions such as those prevailing during the war estimates of the cost of material or labor necessary for the construction of gasoline plants are necessarily high. In 1916 a plant to treat a daily flow of 60,000,000 cubic feet of gas at 250 pounds pressure was built at a cost of about \$1.75 per each 1,000 feet of capacity. A plant for which material was ordered late in 1917 cost \$2.25 per 1,000 feet capacity. Both of these plants were large and did not include gas pumping or cooling systems, but did include compressors to be used on still and on weathering tanks vapors. An installation being erected in August, 1918, to treat 6,000,000 to 8,000,000 cubic feet of gas at 250 pounds pressure will cost between \$25,000 and \$30,000, or about \$3.75 per 1,000 cubic feet of capacity.

Construction costs vary not only with prices for labor and steel but with the pressure and richness of the gas. A tower that will treat 3,000,000 feet a day at 300 pounds being capable of treating not more than 500,000 cubic feet of the same gas at 50 pounds pressure; or if the plant capacity in feet remain the same, the towers for gas treatment will cost six times as much.

The increase because of the greater richness of the gas results from the increased pump, boiler, still, and coil capacity necessary, all increasing with the greater volume of oil circulated to extract the

^a Burrell, G. A., Selbert, F. M., and Oberfell, G. G., The condensation of gasoline from natural gas, Bull. 88, Bureau of Mines, 1915, 106 pp. Dykema, W. P., Recovery of gasoline from natural gas by compression and refrigeration, Bull. 151, Bureau of Mines, 1918, 123 pp.

larger quantities of gasoline. Absorption plants designed to treat casing-head gas under vacuum require the added expense of the pumps, and often of the compressors installed to develop the desired working pressures so that the cost of such plants runs as high as \$40 or \$50 per 1,000 feet of capacity.

ABSORPTION OF GASOLINE VAPOR IN CRUDE OIL.

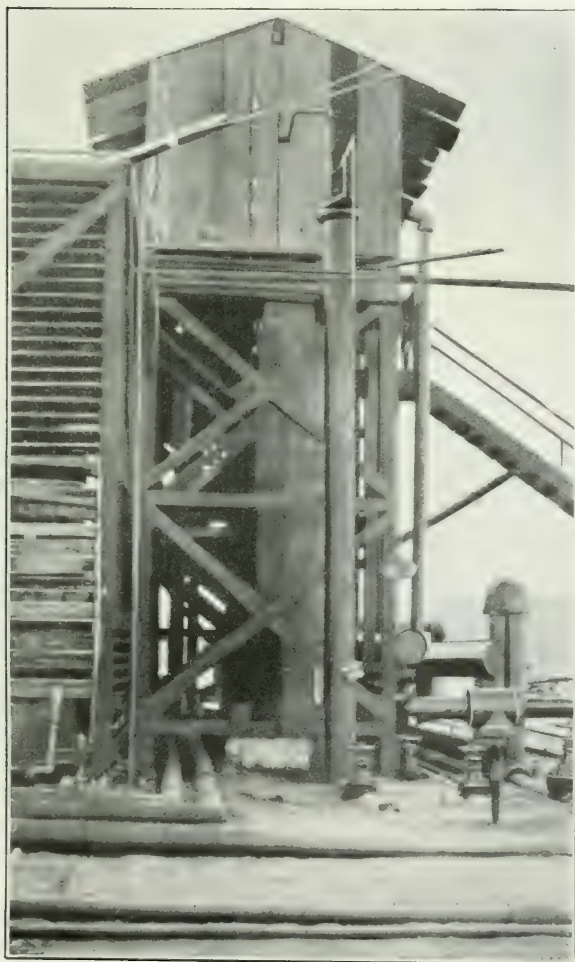
Here it may be of interest to describe a plant that embodies a unique adaptation of the absorption process as developed and used by several of the large California oil companies that produce large quantities of both casinghead and dry gas containing gasoline vapor to make treatment profitable. Instead of using mineral seal oil or other refinery product as the absorbing medium, these companies use the crude oil just as it comes from wells, choosing the heaviest oil produced in the immediate vicinity of the gas pumping station. The gas from the wells is compressed to line pressure and then sent directly through a series of coils cooled with air and water in a louver tower of the usual construction. The coils are made of 2-inch pipe—13 pipes high, 40 feet long—set in headers. From the coils the gas goes to drips or accumulator tanks that separate the small amount of gasoline vapors condensed from the gas by compression and cooling. Then the gas goes to a header connected by short nipples to each of the four towers. These towers are 42 inches in diameter and 20 feet high, are made of riveted $\frac{3}{4}$ -inch to 1-inch plate, and are tested at 300 pounds pressure. In Plate XVIII, *B*, a side view of the battery of towers is shown. The gas from the header connection bubbles up in the towers through the crude oil, which is held by an automatic control (in Plate XVIII, *B*, the 12-inch vertical pipe in the foreground) at approximately 10 feet (one-half the total height) above the bottom of the tower. The tower is two-thirds filled with bricks to break up bubbles as they rise through the oil, the top third of the tower being an open chamber in which the oil and gas can separate. The gas from each tower flows through a short vertical connection to a horizontal header directly above the tower this header collects all the gas from all of the towers, which work in parallel at the same pressure, and from it the gas passes downward through a vertical pipe into the oil trap shown in Plate XVII, *B*. This trap is simple, has no baffles or moving parts, and its design is shown by the illustration. The gas passes out at the left end through the vertical connection, which is connected to the main-line pipe.

OIL CIRCUIT.

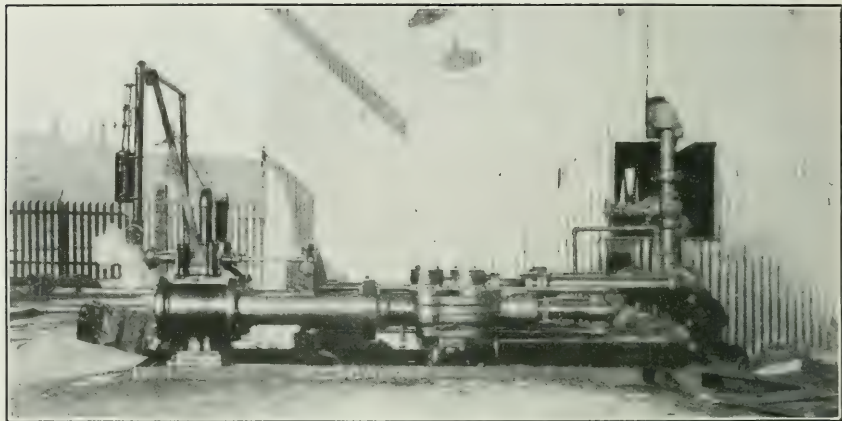
The incoming crude oil is handled by a pump shown in Plate XIX, *A*, from whence it goes to a number of cooling coils set in the louver tower. It leaves these coils at a temperature of 75° F., goes



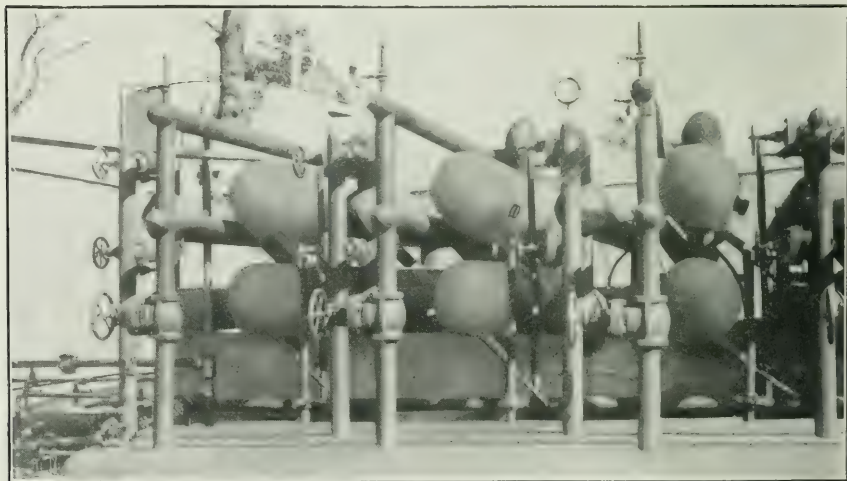
A. VIEW OF DOUBLE-PIPE CONDENSER.



B. ABSORPTION TOWERS FOR CRUDE OIL.



A. PUMP FOR ABSORPTION OIL.



B. WELDED FITTINGS AND PIPE; WORKING PRESSURE, 500 POUNDS PER SQUARE INCH.

directly to the open chamber in the top of towers, passes downward through the towers and back to the storage tanks of the oil pipe-line pumping station. At one of these plants 14,000,000 cubic feet of gas is treated daily, this volume including 6,000,000 cubic feet of "dry" gas, or gas from gas wells, which is compressed to 260 pounds pressure, and 8,000,000 cubic feet of casing-head gas, which is compressed to 150 pounds pressure.

As is the usual practice in the San Joaquin Valley field, the casing-head gas and oil together are permitted to flow under pressure into a trap, when the gas and oil separate. The pressure is maintained to induce the crude to absorb as much as possible of the gasoline fractions during such treatment. A description of gas traps is given in another publication.^a

During a given period 21,300 barrels of crude oil (gravity 21.6° B.) were pumped into the towers, and during the same period 22,729 barrels of oil (gravity 24.7° B.) were taken from the towers, showing an increase of oil of 1,400 barrels, and of gravity of 3.1° B. During a period at a different plant, 12,600 barrels of oil of 19.1° B. gravity were put through the towers, and 14,000 barrels of oil of 23.3° B. gravity were produced. The increase in volume and in gravity is due to dissolved fractions of hydrocarbons contained in gasoline, but as in all other absorption processes, there is probably an increase in Baumé gravity due to dissolved gas and to hydrocarbons, such as propane, that are too light to be held in any great proportion in ordinary motor fuels.

An eastern plant using oil with a gravity of 41° B. as the absorption medium raises the gravity in the absorption towers, under 140 pounds pressure, to 43.9° and actually produces from the oil by distillation about 2 per cent of gasoline, showing that not more than one-half of the 2.9° increase in gravity is due to recoverable gasoline. The light hydrocarbons not recovered and the dissolved gas must account for the balance of the increase.

Companies using this system of drying gas gain a double advantage; besides recovering the gasoline extracted from the natural gas they get the benefit of pumping a more fluid oil through their pipe lines. The exact value of the latter is difficult to compute, but nevertheless it is of decided importance. The operation is continuous, simple, and requires little expense for material and labor, as all of the distilling is done at the companies' refineries several hundred miles from the oil and gas fields. The cost of compressing and cooling the gas can not be charged to the absorption account, as it is a necessary part of the charge for transporting and marketing the gas.

^a Hamilton, W. R., Gas traps for oil wells: Tech. Paper 209, Bureau of Mines, p. 86.

The drying of gas or the recovery of gasoline at plants operated in this way is claimed to be entirely satisfactory, and, whether or not the method is the most efficient that could be used, it undoubtedly shows exceptionally large returns on the investment because of the low first cost and the small expense for operation.

ABSORPTION GASOLINE.

The gasoline obtained through absorbing the lighter hydrocarbons from natural gas and then distilling the absorbent has a high gravity, 72° to 84° B. and a low vapor tension (2 to 5 pounds at 100° F.), so that it commands a premium over the usual "straight"

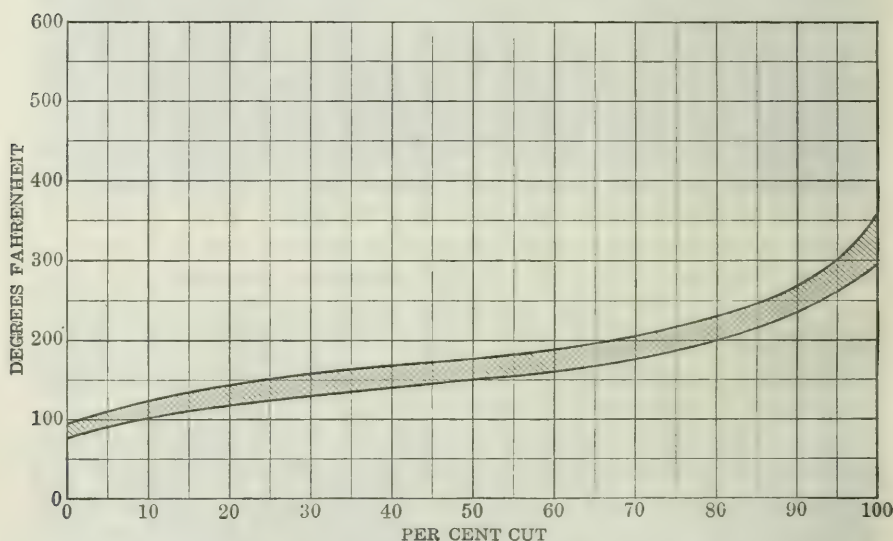


FIGURE 30.—Fractionation diagram for eight absorption-plant gasolines.

run or blended casinghead gasoline. Although it contains extremely light hydrocarbons, it has practically none of the dissolved gases such as make gasoline from compression plants so volatile and practically none of the heavy ends that are often found in "straight" run gasoline as marketed at present. An equal product can easily be made from crude oil by regular distillation, but this would require the heavier fractions now sold as motor fuel to be sold for other use. In fact, it is the general opinion that the greatest part of the absorption gasoline made is used for blending with the heavy fractions from stills, to make the latter a suitable motor fuel.

The gasoline made by the compression of the uncondensed vapors from the coils has practically the same characteristics as the product of plants that compress casing-head gas. It is always blended as fast

as produced, either with naphtha or the still product from the same gas.

The pressures and temperatures used in the treatment of the uncondensed still vapors determine to a large extent the quantity and gravity of the compression product.

Figure 30, which shows a fractionation diagram of eight absorption-plant gasolines, chosen at random from different plants, gives a clear representation of average absorption-plant gasoline.

PLANT RECORDS.

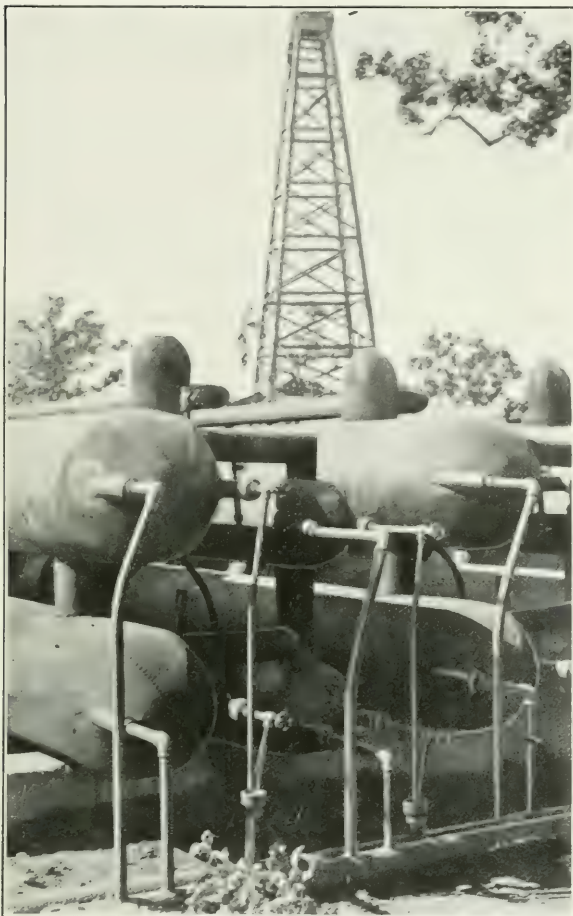
All large gas companies that have operated gas-pumping plants for years keep complete records of all important data. Smaller operators with less experience may find the form below of value as indicating the pressure, temperature, and production records that large operators have found necessary and valuable. Besides its usefulness in checking, records of plant function of this kind holds the interest of men running the plants each tour. By a few recording pressure gauges and thermometers the entire record can be checked; this will show whether recorded figures were read from the instruments or were guesses by the men on tour.

In the accompanying form the daily report sheet used by a large eastern company the entire set of temperatures and pressures is shown as taken at 2-hour intervals, and the total daily records are placed below the hourly readings. Besides the data shown, it is usual to give the number of feet of gas used as fuel in the boilers or for power per gallon of gasoline produced, a figure obtained by dividing the total gas consumed by the total production of gasoline in gallons.

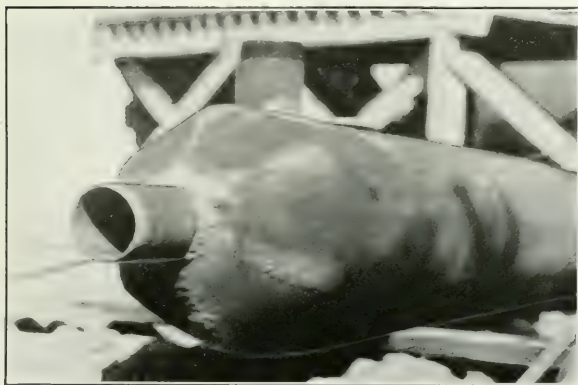
DAILY ABSORPTION GASOLINE REPORT.

From gasoline plant for 24 hours ending 8 a. m., 191..

Nature of observation.	Aver- ages.	No. 1 tour.			No. 2 tour.			No. 3 tour.					
		10 a. m.	Noon.	2 p. m.	4 p. m.	6 p. m.	8 p. m.	10 p. m.	Mid- night.	2 a. m.	4 a. m.	6 a. m.	8 a. m.
Air temperature (in shade).....													
Gas pressure, entering absorber.....													
Gas temperature, entering absorber.....													
Gas temperature, leaving absorber.....													
Oil temperature, entering absorber.....													
Oil temperature, leaving absorber.....													
Oil temperature, entering interchanger (sat.).....													
Oil temperature, entering dephlegmator (sat.).....													
Oil temperature, entering still.....													
Oil temperature, leaving still.....													
Oil temperature, leaving interchanger (unsat.).....													
Oil temperature, leaving cooler (unsat.).....													
Water temperature, entering condenser.....													
Water temperature, leaving condenser.....													
Gasoline temperature, vapor leaving still.....													
Gasoline temperature, vapor leaving dephlegmator.....													
Gasoline gravity, leaving condenser.....													
Gasoline temperature, receiving tank.....													
Gas used for fuel under boiler.....													lb.
Gas passed through absorbers.....													gal.
Gasoline produced.....													gal. per 1,000 cu. ft.
Gasoline produced.....													lb.
Gravity gasoline, before pumping into storage; run of tank No. 1,.....													Number of absorbers used
Total absorbent oil on hand in storage tanks this morning.....													Vel. of gas in absorbers
													ft. per min.
													Chief Engineer.
													Engineer No. 3 tour.
													Engineer No. 2 tour.
													Engineer No. 1 tour.



A. WELDED HORIZONTAL ABSORBERS.



B. EIGHTEEN-INCH PIPE REDUCED TO 4-INCH NIPPLE BY CUTTING AND WELDING.

OXY-ACETYLENE WELDING.

In this paper are illustrations that show many units which are partly or wholly of welded construction. The testing apparatus is almost universally welded, welding being especially suitable for small work of that character.

Many of the more progressive operators have carried welding much further than simply as an alternative for small fittings, using it to replace practically all fittings except valves. Plates XIX, *B* (p. 73), and XX, *A* show how this process may be used in complicated units. The plant illustrated worked at pressures ranging up to 500 pounds per square inch, yet had no trouble with any of the welded joints. Plate XX, *B* shows a near view of an 18-inch standard pipe reduced to take a 4-inch nipple which is also welded in.

Some operators claim that a welded pipe line will not hold high-gravity compression gasoline because the welding burns the carbon out of the iron in the weld, leaving it so porous that "wild" gasoline under line pressures would penetrate every joint. In regard to this claim Mr. J. J. Allison, chief engineer of the Empire Gas & Fuel Co., says: "The strength and tightness of a weld depends entirely upon the welder; competent, skilled men can make welded joints that are as strong and tight as joints made with fittings, and the welded work is often better and less expensive."

SUMMARY.

USES OF TESTS.

In the foregoing pages the writer has described the absorption-plant operations in successful use at the many plants visited. Although many changes and improvements have been made since the first horizontal units were started, yet the industry has not reached a standard of units, for many experiments are being made at almost every plant to advance efficiency, to improve the product, and to lower costs.

Teaching plant foremen and shift men to use testing apparatus for both absorption efficiency and specific gravity is one of the first steps toward improvement. These operations are simple and easy; they hold the interest of the force, and also give a continuous record of the performance of the various units. Not only should both absorption and specific gravity tests be made of the incoming and treated gas, but also of the still vapors from the cooling coils and from the last unit, whether a compressor or another small absorption tower.

GAS TREATMENT.

QUALITY OF GAS.

Any gas containing the hydrocarbons that constitute the gasoline content can be treated by absorption for the recovery of these hydrocarbons. Rich casing-head gas and still vapor containing as much as 4 gallons of gasoline per 1,000 cubic feet are being successfully and efficiently treated, the gasoline content merely being a factor in the quantity of oil circulated. The process started, however, in the drying plants of companies pumping lean or "dry" gas which yields only a pint or less per 1,000 cubic feet and this fact led to the general impression that richer gases were not amenable to the process.

PRESSURE NECESSARY.

The pressures being used in the absorption process range from atmospheric to 500 pounds per square inch. Although it is true that gases containing all proportions of gasoline may be treated at all pressures, there are practical limitations of construction and size of units.

EFFECT OF TEMPERATURE.

Gas should always be cooled to as low a temperature as is practicable without an undue expense for an artificial cooling plant. The primary reason for cooling is that at low temperatures a given quantity of oil will absorb greater quantities of gasoline; moreover gasoline of a low boiling point will not be recovered by oil at temperatures higher than that point. Thus low temperature not only increases the total production but also permits a higher percentage of saturation of the oil thereby reducing the total oil circulated. Consequently the pumps, still, and other units have to do less work and fuel is saved. The oil sent to the towers should have a correspondingly low temperature for the same reasons.

EFFECT OF PRESSURE.

Although any pressure may be used in conjunction with the quantity of oil in towers, the pressure determines the actual volume of the gas, and this volume is a function of the velocity of flow through a tower or a given cross section. Thus the pressure controls the cross section or diameter of the towers to be used, since if rate of flow is too great, oil is carried over mechanically and the oil and gas are in contact too brief a time to obtain the desired extraction. Flow velocities over 75 feet per minute in the unbaffled or open part of the tower are too rapid, so that with such velocities the gas will usually carry oil with it from the tower.

The diameter of the towers used ranges from 18 inches to 12 feet and the pressures from a few ounces to 500 pounds, the low-pressure towers being the larger. For high pressure (100 pounds and over) the strength of pipe or metal necessary limits the diameter. The largest high-pressure tower seen in operation was 36 inches; the pressure used was less than 300 pounds.

HEIGHT OF TOWER.

The percentage of gasoline that is absorbed by the oil is, within the limit of total saturation, controlled by the duration and intimacy of the contact between the oil and gas and the temperature of the two. The duration is controlled by the velocity of the gas and by the height of the effective or baffled part of the tower. This fixes the height of the tower as a function of the saturation desired or possible. Thirty-foot towers are yielding saturations as high as 6 per cent, and aggressive operators are planning 40-foot towers in the hopes of increasing this figure to 10 per cent with the aid of more efficient baffling materials. If this increase can be had without hindering the com-

plete recovery of gasoline, the saving of fuel will be well worth the cost and effort.

BAFFLING.

Many substances have and are being tried for baffling in towers, the object being to obtain material that will leave the greatest open space for the flow of gas and still break the gas into many fine streams that are continually divided and mixed, and in addition will expose a maximum surface of the absorbent to the gasoline vapors.

Wood gratings of many dimensions have been used in different plants and while the work done by them is satisfactory they constrict the tower section unduly and prevent the passage of the greatest volume of gas; that is, they cut down the capacity. Stone filling has the same effect but to a greater degree.

Chemical stoneware, blocks or tile, are being used successfully, but they also have a large bulk (50 per cent), which is absolutely inactive as far as concerns useful work. Hollow building tile are also used; they give satisfactory results but lessen the openings considerably. Steel cuttings are being tried, and, so far as the experiments have been carried, seem to give better promise than other material. One company is using 15 pounds of steel cuttings per cubic foot of tower, a porosity of 97 per cent. Another operator uses 30 pounds of the cuttings per cubic foot and has a porosity of 94 per cent. In addition to this high percentage of voids, the material offers an exceptionally large surface for exposing the oil to the gas.

The gas after passing out of the towers is taken through a trap, where any oil carried out of the tower with the gas is separated and run back to the weathering tanks.

OIL CIRCUIT.

COOLING COILS.

Oil entering the towers should be as cool as is economically possible. To obtain this temperature the cooling is done in towers under water sprays. An area of 3 square feet of radiating surface per gallon per minute is abundant, provided the pipe used is 2 inches in diameter and is placed in a well-designed and properly constructed cooling tower.

QUANTITY OF OIL CIRCULATED.

The quantity of oil circulated per 1,000 cubic feet of gas depends upon the gasoline content of the gas, the pressure, the temperature of both the oil and gas, and the vapor tension of the absorbing medium. Vapor tension is largely determined by temperature. As an interesting example of this fact, a company is using gasoline as the absorbent,

the vapor tension of the gasoline being reduced by the use of an ammonia cooling plant to the point that permits absorption. In this plant the product from the tower is a marketable motor fuel and, consequently, redistilling is unnecessary. It is questionable, however, whether equipment for ammonia cooling can be erected and operated at nearly as low a cost as a still, which, in this instance, it replaces.

Obviously, gases rich in gasoline vapors require large quantities of oil; and as the absorbing power of an oil increases with the pressure, the higher the pressure used the less oil need be sent through the tower.

Plants using pressures of 100 pounds and higher run the saturation as high as 6.5 per cent, and many operators believe that by increasing the height of the towers 50 to 100 per cent this figure may be increased to 10 per cent. In plants using lower pressures (atmospheric to 30 pounds) the saturation percentage can not be brought as high, 2 to 4 per cent being good practice under present conditions. The richness of the gas in gasoline vapor is of little moment as regards saturation percentages.

From the towers the oil is run through automatic traps to a weathering tank. In this tank, which is held at low pressures (atmospheric to 30 pounds) the dissolved gases are allowed to separate from the oil so that the following units do not have to treat this gas, a consideration of importance in large, high-pressure plants. The gas would also dilute the vapors from the still, causing a lower percentage of precipitation in the coils. These gases with the undensified vapors from the still are at many plants treated by compression or in a small absorption unit working under low pressure.

After half an hour to 2 hours weathering the oil is either pumped through the heat interchanger or allowed to flow through it under the pressure held on the weathering tank.

HEAT INTERCHANGERS.

Although many types of heat interchangers have been installed, the industry at present appears to have discarded all types except the jacketed line. Such interchangers are either made of two pipes, one within the other, each containing oil flowing in opposite directions, and connected in series; or of a large pipe with a number (five to eight) of smaller (1-inch to 2½-inch) pipes inside of it so arranged as to give a continuous counter flow of oil.

On its way to the still the oil is heated as high as 170° F. whereas the oil from the still is cooled to 130° F. The interchanger effects two savings, first in the boiler power for heating the oil, and second in the water pumped and the coil area for cooling the unsaturated oil going to the towers.

In coils of the type most used in radiating area of 0.25 to 0.35 square feet is allowed for each gallon per hour passing through the unit on its way to the still.

STILLS.

With the exception of experiments being made in baffling material for towers, no part of absorption plants is now receiving more attention than the still. The older plants all used the type steam still used in refineries, but this has proved inefficient in absorption practice. Such stills are of large (8 to 12 feet) diameter and 16 to 30 feet long. They are held one-third to two-thirds full of oil, which is all partly treated and continuously dilutes the freshly saturated entering oil. As it is the last 1 or 1½ per cent of gasoline contained in the oil that is difficult to separate and send out as a vapor, the continual dilution keeps the saturation of the oil in the still at the point where the vapors are most resistant; hence the distilling action requires excessive time as well as an undue amount of heat.

The pan type of still seems to overcome at least part of these objections, as the oil flows through in a small stream while being heated by the steam coils and being treated with live steam in the bottom of the still. The entire operation requires only a few minutes and the separation of the gasoline fractions is accomplished more easily and thoroughly.

One operator is trying a vacuum still to operate at low temperatures, while another is experimenting with a combination fire and steam still. The results are not complete but show promise of interesting results.

VAPOR TREATMENT.

In distilling an absorption oil with open steam coils (which are necessary if the gasoline is to be vaporized at the temperatures used) not only the gasoline vapors, but vapors of the heavier fractions are driven from the absorption oil itself and these with the uncondensed steam leave the still together.

It is now the usual practice to pass this mixture of vapors through some apparatus by which their temperature is reduced through a transfer of heat to the oil entering the still. This transfer of heat is obtained either by direct contact between the oil and vapors or with a heat exchanger of the preheater type, in which the oil and vapors are separated by the walls of tubing.

The object of this interchange is to precipitate as much as possible of the heavy oil and water vapors without condensing the gasoline vapors and also to recover a part of the heat from these vapors.

From an open contact, or stone tower, which seemingly is not very efficient, the vapor mixture has to be cooled further in water-cooled coils held at temperatures between 180° and 190° F. in order to remove completely the heavy absorption-oil fraction carried over. This "knock-out" coil has not been used in plants with a preheater type of unit at this point in the circuit. None of the absorption oil should be allowed to pass this point, as it would condense with and discolor the gasoline. A part of the water vapor will pass this point, but when this condenses with the gasoline it is easily separated by the gravity or the overflow method.

After this point, whether a water-cooled coil or an interchanger be used to precipitate the absorption oil, the gases (gas, gasoline, and water vapors) are further cooled in water-cooled coils.

FINAL COOLING COILS.

The vapors are often cooled in submerged coils of 2-inch, 4-inch, 6-inch, or 8-inch pipe, having an area of from 2 to 4 square feet per gallon of gasoline per hour. As previously stated, this type of coil is rapidly being replaced by the spray-cooled coils in louver towers, which in most respects are far better. Spray-cooled coils are almost universally of the continuous return-bend type, made of 2-inch pipe, enough coils being taken out of a header to care for the volume of gas and vapor to be cooled. The total length of pipe or number of coils of given length is computed on a basis of 2 to 3 square feet of radiating area per gallon of gasoline condensed per hour.

The reduction in temperature should cool the vapor as much as the absorption oil and gas entering the towers are cooled; that is, as low as is possible with cooling by water sprays.

Gasoline and water are condensed to liquids in these coils and are separated together from the gas. Later the gasoline and water are separated by gravity in any one of the simple apparatus for this purpose or the water is drawn from the bottom of a "make" tank.

The gas from these coils carries some condensable gasoline vapors, and is further treated by compression or with a small (8 inches or 10 inches by 20 feet high) absorption tower. The writer favors the latter method. Oil for this tower is taken from the high-pressure oil line leading to the larger towers, and the saturated oil from the towers is sent directly to the still. Between 10 and 25 per cent of the total plant production of gasoline is usually recovered by this treatment. Some operators mix the weathering tank gas with the cooling-coil gases before this final treatment, but the value of this practice is doubtful.

THE PRODUCT.

Gasoline made by the absorption process is especially sweet, has a high gravity (70° to 85° B.), and as it comes from the still has a low (3 to 6 pounds) vapor tension.

Commanding through these properties a premium in the open market, absorption gasoline is a more profitable product than either raw or blended compression condensate. For this reason and because absorption plants cost less to install per 1,000 feet of capacity and are more efficient than any others in use, absorption plants seem likely to supersede compression and refrigeration plants for recovering gasoline from natural gas.

PUBLICATIONS ON NATURAL GAS AND INDUSTRIAL GASES.

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